PHYSICAL OCEANOGRAPHY OF THE GULF OF MAINE

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INTRODUCTION

This memoir is the third and final part of the general report on the oceanographic survey of the Gulf of Maine.[1]

Key charts to the stations will be found in the preceding part of this volume (Bigelow, 1926, figs. 1–9); the dates and positions are tabulated below (p. 976) with the physical data.

The chapter on hydrodynamics has been made possible by Lieut. Commander E. H. Smith's collaboration; R. Parmenter tabulated the physical data for the *Fish Hawk* cruises of 1925, collaborating also in the charts and discussion based thereon;

Records of temperature or salinity have been contributed by R. A. Goffin, Wm. C. Schroeder, Capt. G. W. Carlson, Capt. G. W. Greenleaf, C. G. Corliss, and Dr. C. J. Fish of the Bureau of Fisheries. Capt. John W. MacFarland, from his schooner *Victor*, and Henry Stetson and T. C. Graves, from their yachts, also have taken welcome observations.

I owe a debt of gratitude also to Dr. A. G. Huntsman, who has generously allowed quotation from his report on Canadian drift-bottle experiments in advance of publication, and who contributed other data acknowledged in the appropriate connections; to Dr. J. P. McMurrich, who has offered the use of his unpublished data on temperatures at St. Andrews, New Brunswick; and to the late Dr. A. G. Mayor, who contributed the colorimetric tubes used in the determination of alkalinity on the *Albatross* and *Halcyon* cruises of 1920–21.

OCEANOGRAPHIC HISTORY

1. GULF OF MAINE PROPER

The first Gulf of Maine temperatures, so far as I can learn, were taken in October, 1789, by Benjamin Franklin's nephew, Jonathan Williams, who read the "heat of the air and water at sunrise, noon, and sunset" (1793, p. 83) on a voyage from Boston to Virginia, and found the surface 8.9° C. (48° F.) off the mouth of Massachusetts Bay on October 11, warming to 11.1° (52° F.) off Chatham on Cape Cod, to 15° (59° F.) over the outer part of the continental shelf south of Nantucket, and to 18.3°–19.4° (65° to 67° F.) in the inner edge of the Gulf Stream outside the edge of the continent on the 13th—readings that agree very well with the usual distribution of temperature for that season. On another voyage (from Halifax to New York) during the last week of July, 1790, he again took temperatures on Roseway Bank, Browns Bank, and in the gully between them; also along the southern side of Georges Bank (53° to 64° F.).

Enough readings of the surface temperature of the Gulf of Maine had accumulated during the first half of the nineteenth century to permit Maury (1855 and 1858) to show its coastal belt and the Bay of Fundy as between 50° and 60°, its southern side out to the continental edge as between 60° and 70° in July, and the entire gulf as colder than 50° in March.[2]

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[1] The first part was devoted to the fishes (Bigelow and Welsh, 1925); the second to the plankton (Bigelow, 1926).

[2] Petermann (1870) more correctly interprets the individual readings reproduced on Maury's (1852) thermal chart by showing the inner parts of the Gulf of Maine as 54.5° to 59° and the Georges Bank-Nantucket Shoals region as about 59° to 65.5° in July about 32° and 32° to 41°, respectively, in January

The first attempt to measure the temperature of the gulf below the surface was made in the summer of 1870, when Verrill (1871, p. 3) found the water virtually homogeneous, surface to bottom, in Passamaquoddy Bay, though readings with thermometers of the maximum-minimum type established a considerable range of temperatures on the offshore slope of Georges Bank (Verrill, 1873; Sanderson Smith, 1889, p. 887).

Two summers later surface and bottom temperatures were taken at a large number of stations in the neighborhood of Casco Bay from the Fish Commission steamer *Blue Light* (Verrill, 1874, 1874a), and also at various localities in deep water in the western side of the gulf by the Coast Survey steamer *Bache* (Sanderson Smith, 1889, p. 885; Packard, 1876). As a result of this summer's work Verrill was able to bring to scientific attention the contrast between the low bottom temperature and the warm surface of the western side of the gulf.

The survey was continued by the *Bache* in the summer of 1874 at about 40 dredging stations in the western side of the Gulf of Maine, in depths of 27 to 113 fathoms (Sanderson Smith, 1889, p. 886). No observations were taken in the gulf in 1875 or 1876; but in 1877 the Fish Commission, from the *Speedwell,* in connection with a survey of the bottom fauna, took surface and bottom temperatures in the northern part of Massachusetts Bay, with serial observations at several stations on a line crossing the gulf to Cape Sable.

Unfortunately, none of the subsurface temperatures taken in the gulf up to that date were even approximately dependable, according to present-day standards, because the Miller-Casella thermometers employed were not only unreliable (Verrill, 1875, p. 413), but, being of the maximum-minimum type, they would register merely the lowest temperature at each station, which was not necessarily at the level at which the reading was ostensibly taken. Modern oceanographic research in the gulf may therefore be dated from the summer of 1878, when the *Speedwell* took temperatures in Massachusetts Bay and off Cape Ann, including serials at 31 stations (Sanderson Smith, 1889, p. 905; Rathbun, 1889, p. 1005), with reversing thermometers. This type, improved from time to time, has been employed regularly ever since. The *Speedwell* worked again in the gulf in the summer of 1879 (Sanderson Smith, 1889, p. 909; Rathbun, 1889, p. 1006). In June, 1880, the *Blake* took surface and bottom readings at three stations inside the 200-fathom contour on the eastern part of Georges Bank (Rathbun, 1889, p. 972, and A. Agassiz, 1881), while in August the *Fish Hawk* obtained similar data off Chatham, Cape Cod, in 10 to 43 fathoms (Rathbun, 1889, pp. 922–923), but did not visit the more northern parts of the gulf.

The year 1882 is an important one in the annals of North American oceanography, because that spring saw the oft-quoted destruction of the tilefish[3] and of the invertebrate fauna that inhabited the warm band along the edge of the continent, presumably by flooding with very cold water. During the following August the *Fish Hawk* took observations south of Marthas Vineyard and made one trip to the 100-fathom line east of Cape Cod (Rathbun, 1889, p. 925).

Surface and air temperatures were recorded from early spring to late autumn at several lighthouses and lightships along the coast of the gulf from Nantucket Shoals to Petit Manan during the years 1881 to 1885, the 10-day averages of which are

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[3] For an account of this event and of the gradual reestablishment of the species see Bigelow and Welsh, 1925.

tabulated by Rathbun (1887). The very large number of temperatures taken on the lightships in the ordinary routine since that time have not been examined critically, however.

The *Albatross* occupied a large number of dredging stations along the offshore slope of Georges Bank during 1883, 1884, 1885, 1886, and 1887, but only five of her serial readings and a few of the bottom records fall within the limits of the Gulf of Maine.[4] An extensive series of temperatures taken by Dr. W. C. Kendall at the surface and at small depths in the western part of the gulf, in connection with mackerel investigations carried out by the *Grampus* in 1897, also deserves mention (p. 594).

A gap follows in the thermal history of the gulf until the summer and autumn of 1904, when the Tidal Survey of Canada took a large number of surface and subsurface temperatures in the Bay of Fundy region and off the west coast of Nova Scotia (Dawson, 1905, 1922). Many of these were repeated in 1907. In July, 1908, a few readings were taken from the *Grampus* in the region of Nantucket Shoals.

The reestablishment of the biological station of the Biological Board of Canada at St. Andrews, at the mouth of the St. Croix River, in 1908 marks an epoch in the oceanographic study of the Bay of Fundy region. The first published survey of the temperature and density (the latter determined by hydrometer) in the neighborhood of St. Andrews was carried out in July, 1910 (Copeland, 1912). Since then the taking of temperatures and of salinity has been a regular part of the station's work, and such of the data as have been published are mentioned below.

Although the preceding summary may seem somewhat formidable, very little was yet known of the subsurface temperatures of the offshore parts of the gulf, even in summer, for only one small area in its western side had been examined with satisfactory instruments. Nor had anything been learned of its winter state or of the salinity of its deep waters at any time of year until 1912. In that year the United States Bureau of Fisheries and the Museum of Comparative Zoology jointly undertook the general oceanographic exploration of the gulf, which, continued to date under my direction, has been the foundation of this report and of those that have preceded it (Bigelow, 1914 to 1926; Bigelow and Welsh, 1925).

The first fruits were the serial records at 46 stations (10001 to 10046) in the northern half of the gulf during that July and August (p. 978; Bigelow, 1913, 1914), including the first determinations of the salinity of the water of the gulf by the titration method (p. 976) that for some years had been in general use on the other side of the Atlantic. This, subsequently, has been a routine part of our station work. Observations were taken bimonthly off Gloucester by the *Blue Wing* during the winter of 1912–1913; north of Cape Cod during the following spring by W. W. Welsh (stations 10047 to 10056; W. W. Welsh stations 1 to 32; and Bigelow, 1914a); also a few temperatures and water samples between Massachusetts Bay and Georges Bank by Thomas Douthart and W. F. Clapp (table, p. 980).

The *Grampus* carried out a general survey of the western and northern parts of the gulf in the summer of 1913 (stations 10057 to 10061, 10085 to 10112, p. 982; Bigelow, 1915), as well as of the coastal waters between the longitudes of Marthas Vineyard and Chesapeake Bay. This was followed by a more comprehensive oceanographic examination of the offshore banks, as well as of the inner parts of the gulf and of the coastal

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[4] For these *Albatross* data see Townsend (1901, dredging stations 2053, 2054, 2060–2064, 2068, and 2522).

shelf eastward along Nova Scotia to Halifax in the summer of 1914 (stations 10213 to 10264, p. 985; Bigelow, 1914b, 1917). Temperatures and water samples (density of the latter determined by hydrometer) were taken at many localities in the Bay of Fundy region that summer and the following winter from the biological station at St. Andrews (Mavor, Craigie, and Detweiler, 1916; Craigie, 1916, 1916a; McMurrich, 1917; and Doctor McMurrich's unpublished plankton lists). In 1915 the *Grampus* cruised in the gulf from spring to midautumn (stations 10266 to 10339, p. 987; Bigelow, 1917). Craigie (Craigie and Chase, 1918) likewise took serial temperatures in the Bay of Fundy, in Annapolis Basin, and in St. Marys Bay, as well as salinities in the latter (Vachon, 1918).

That same summer is memorable in oceanographic annals for the general survey of eastern Canadian waters carried out by the Canadian Fisheries Expedition (Hjort, 1919; Sandström, 1919; Bjerkan, 1919). This, however did not touch the Gulf of Maine region except for one profile crossing the shelf off Shelburne, Nova Scotia, in July.

It is a fortunate chance that the western and southwestern parts of the gulf, on the one hand (stations 10340 to 10357, 10398 to 10404; Bigelow, 1922[5]), and the Bay of Fundy, on the other (Vachon, 1918), both were studied in 1916, for that summer and autumn followed an almost Arctic winter and a backward spring.

Exploration of the offshore waters of the Gulf of Maine was interrupted by the war, except that serial observations were taken at a station between Grand Manan and Nova Scotia by the St. Andrews station at intervals from 1916 to 1918.

In 1919 work was resumed, when the United States Coast Guard cutter *Androscoggin*, on ice patrol, ran profiles across the gulf in March, April, and May (United States Coast Guard stations 1 to 3, 19 to 22, 35 to 38, p. 997; E. H. Smith, 1924, p. 103), while Mavor (1923) made an oceanographic survey of the Bay of Fundy in August. Study of the surface currents of the Bay of Fundy by drift bottles also was inaugurated by the St. Andrews station during that summer (Mavor, 1920 to 1923), and later was expanded into a joint project to cover northeastern American waters generally.

Prior to 1920 attention had been directed chiefly to the state of the gulf during the warm half of the year. To remedy this seasonal deficiency the *Albatross* carried out a general survey of the entire region from February to May, 1920 (stations 20044 to 20129, p. 998; United States Bureau of Fisheries, 1921), while the *Halcyon* cruised in the northern half of the gulf during the following December, January, and March. The *Halcyon* also occupied a net of oceanographic stations in Massachusetts Bay during August, 1922, and has made scattered observations at various seasons since then (stations 10631 to 10645, p. 995, and unnumbered stations, p. 1012). Finally, the *Fish Hawk* took temperatures and salinities at many stations in Massachusetts and Cape Cod Bays at intervals during the winter and spring of 1924–25 (p. 1004).

The following lines of drift bottles have been set out in the Gulf of Maine since 1919: July, 1922, one line running southeasterly from Cape Elizabeth to the center of the gulf; another from the southern angle of Cape Cod southeasterly out across the edge of the continent; and likewise a line off New York. A line also was set out

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[5] The operations of the *Grampus* in 1916 were in the immediate charge of W. W. Welsh.

off Cape Sable that summer by the Biological Board of Canada, besides several other lines farther east (p. 908). During August, 1923, lines of bottles were set out normal to the coast line off Mount Desert, Cape Elizabeth, Cape Ann, and Cape Cod (p. 874); and a much larger number of bottles was put out in more eastern Nova Scotian waters by the Biological Board of Canada, some of which have drifted to the Gulf of Maine, as described below (p. 908). No bottles were put out in the Gulf of Maine proper in 1924, although lines were run across Vineyard and Nantucket Sounds. Some of the many Canadian bottles put out that summer off the outer coast of Nova Scotia have been picked up in the Gulf of Maine. Finally, bottles were put out in Massachusetts and Ipswich Bays in February, April, and May, 1925; in Massachusetts Bay again by Henry Stetson in April, 1926, and off Cape Nedick by T. E. Graves that July, from their yachts (pp. 878, 879).

The measurements of currents, which have been taken in the gulf by the Tidal Survey of Canada and by the United States Coast and Geodetic Survey, are mentioned in a later chapter (p. 857).

2. CONTINENTAL SHELF SOUTH OF NANTUCKET AND MARTHAS VINEYARD

The earlier explorations in this area are summarized in a previous report (Bigelow, 1915), hence they may be passed over briefly here.

The general range of surface temperature south of Woods Hole is now well known for the summer season, thanks to the early explorations by the vessels of the Bureau of Fisheries, notably in 1880 to 1882 (Tanner, 1884 to 1884b) and in 1889 to 1891 (Libbey, 1891, 1895). Daily records of temperature of air and water also have been recorded for many years at Woods Hole,[6] and observations have been taken on the various collecting trips carried out summer after summer from that station. Dickson (1901) likewise has collected a large number of surface temperatures from the logs of vessels, and the *Grampus* has crossed this part of the continental shelf on several recent cruises.

A large number of subsurface temperatures and determinations of salinity by hydrometer also have been taken from Marthas Vineyard and Nantucket out to the edge of the continent and beyond, beginning with the early dredging trips of the vessels of the Fish Commission (1880 to 1881[7]) and continued by Libbey in 1889, 1890, and 1891. Libbey continued his study in subsequent years, but the results never have been published; nor, except in a few instances, have the bottom temperatures taken subsequently on the various dredging trips sent out to the waters south of Marthas Vineyard from the Woods Hole station of the Bureau of Fisheries.

In 1908 the *Grampus* took temperatures in 31 to 400 fathoms southward from Nantucket Shoals (p. 595; Bigelow, 1909). In July, 1913, she occupied several oceanographic stations in that general region, working southward thence to Chesapeake Bay (Bigelow, 1915; stations 10062 to 10084). During that August she took surface temperatures from Cape Cod to Cape May (Bigelow, 1915, p. 350); in 1914

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[6] These are summarized by Sumner, Osburn, and Cole (1913) and by Fish (1925).

[7] For records of temperature during this period, see Sanderson Smith (1889); for the *Albatross* stations, see Tanner (1884a, 1884b) and Townsend (1901).

and 1915 she ran oceanographic profiles across the slope abreast of Marthas Vineyard in August and October, mentioned above (p. 517). In 1916 she again made summer and November cruises from Gloucester to Chesapeake Bay (Bigelow, 1922).

TOPOGRAPHY

The indentation of the coast between Cape Sable, at the southeast angle of Nova Scotia on the east, and Cape Cod and Nantucket Island, on the west, seems to have gone unnamed until late in the last century, when it was christened "Gulf of Maine." As outlined by the coast, the gulf is roughly rectangular, much wider (about 200 miles) than deep (about 120 miles). It is a far better marked natural province below the surface of the sea than the shallow recession of its shore line would suggest, for its southern boundary is marked by a shallow rim, or "sill," pierced by three narrow passages only. Passing eastward from Nantucket, with its off-lying shoals, these, successively, and the banks that separate them, are: The South Channel (not very well defined and only 40 to 50 fathoms deep), Georges Bank, the Eastern Channel, Browns Bank, the Northern Channel, and finally the Seal Island or coastal bank off Cape Sable. This rim, as Mitchell (1881) long ago pointed out, 259 miles in length from Nantucket to Cape Sable, follows, in its main outlines, the arc of a circle whose radius is about 167 miles. Along this arc the length of Georges Bank, from the deepest trough of the South Channel to the 50-fathom contour on the slope of the Eastern Channel, is about 140 miles, with a greatest breadth of about 80 miles from north to south between the 50-fathom contours. Between these same contours of the Eastern Channel and of the Northern Channel each occupies about 25 miles of the arc. In round figures, the area of Georges Bank is 10,000 square miles; that portion of Browns Bank west of longitude 65° 30′ W. (taken as the arbitrary boundary of the region under discussion) is about 550 square miles.

The area of the gulf north of the rim is given by Mitchell as about 36,000 square miles. The coast line of the gulf, as it would appear on a small-scale chart, follows a fairly regular curve, but in detail it is extremely complex; for the northern and eastern shores are not only frequently and deeply embayed, but are bordered by a perfect labyrinth of islands, large and small, extending in places 10 to 20 miles seaward from the mainland. Its largest bays (Massachusetts on the southwest and the still larger Bay of Fundy on the northeast) are too well known to need more than passing mention.

The coast of the Gulf of Maine falls into two main types, Cape Elizabeth marking the transition from one to the other. South of this headland the shore line is characterized by a succession of sand beaches alternating with bold headlands, notably Cape Ann, and with rocky stretches, which in Cape Cod Bay give place to the continuous sand strand of the cape. Along this part of the coast there are but few islands, except in Boston Bay, and the fjord type of indentation is notably absent. East of Cape Elizabeth, on the contrary, the shores of the State of Maine are almost continuously rocky, as are the islands of the outlying archipelago already mentioned; and deep bays succeed each other in close succession as far as the mouth of the Bay of Fundy. As a whole, the shores of the gulf are low, seldom rising to more than 100 to 200 feet in the immediate neighborhood of the sea; but the Camden hills and the mountains of Mount Desert (with the maximum elevation of 1,500 odd feet) are exceptions to this rule, while the cliffs of the north shore of Grand Manan rise to a height of 200 to 300 feet, almost sheer from the water.

DEPTH OF THE GULF[8]

If we take the 50-fathom (virtually the 100-meter) contour as marking the confines between the peripheral and central parts of the gulf (a natural boundary, because this level not only outlines the northern slope of Georges Bank but includes virtually all the outlying islands), the coastal shallows to the east, north, and west and the rim on the south inclose a bottle-necked basin that communicates with the open sea by two narrow channels only—the eastern and northern. The Eastern Channel, at its narrowest point between Georges and Browns Banks, is about 140 fathoms (256 meters) deep along its trough; the Northern Channel is 65 to 80 fathoms (120 to 145 meters), with a maximum of 78 fathoms (143 meters) in the narrows between Browns Bank and the Coast Bank. North of the rim the deepest water (100 fathoms, or 200 meters and over) takes roughly the form of a Y, with its two arms extending westward and northeastward. As these two troughs apparently were unnamed, I have christened them the "western" and "eastern" basins. They join in the southeast corner of the gulf, where they are continuous with the Eastern Channel. As Mitchell (1881) has pointed out, more than 10,000 square miles of the gulf are deeper than 100 fathoms. The gulf is deepest just inside the entrance to the Eastern Channel and close to the northern slope of Georges Bank as a trough some 50 miles long (west and east), with 150 fathoms (275 meters) or more, and a maximum of 184 fathoms (336 meters). There is also a second, smaller bowl, deeper than 150 fathoms (180 fathoms, or 329 meters, maximum) in the inner part of the western branch of the Y, off Cape Ann.

Over the south-central region of the gulf (that is, the region of union of the two arms of the basin) the depth is generally from 100 to 120 fathoms (180 to 220 meters), varied, however, by many shoaler spots of 90 to 100 fathoms and by occasional deeper soundings of 120 to 135 fathoms (220 to 250 meters). The configuration of the bottom makes the fathom a more instructive basis for contour lines than the meter in just this region; for whereas the 100-fathom curve includes the whole basin, the 200-meter contour, though differing so little in actual depth, is much interrupted here by ridges of 180 to 190 meters, obscuring the essential troughlike conformation of the basin. In the western arm of the basin the water is deepest 45 miles east of Cape Ann; in the eastern arm it is deepest in the extreme northeast corner (145 fathoms, or 265 meters). In both branches the general level of the basin floor is from 115 to 130 fathoms (210 to 238 meters).

BANKS AND SINKS

Isolated sinks or pot holes are numerous; indeed, the deeps of the two basins just mentioned are such. Most of these do not fall deep enough below the surrounding bottom to call for any special comment, but three such bowls are so deep

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[8] On the ordinary navigational charts of the region, published by the United States Coast and Geodetic Survey and the United States Hydrographic Office, the depths are given in fathoms. Consequently, the following discussion is also in fathoms, but with the equivalents in meters also stated.

and are inclosed by rims so much shallower that they have been made the field of considerable hydrographic investigation. These, for want of better names, I may christen (1) the Cape Ann sink, lying near Stellwagen Bank, centering about 12 miles southeast of Cape Ann, having a general depth of 50 to 70 fathoms (91 to 128 meters) and a greatest depth of 99 fathoms (181 meters), and inclosed by a continuous rim of 40 fathoms (70 to 75 meters) or shallower; (2) the Isles of Shoals sink, centering 28 miles northeast of Cape Ann, having a general depth of 80 to 100 fathoms (146 to 183 meters), and inclosed on the south and east by the shallows of Jeffreys Ledge and on the north by depths of 60 to 70 fathoms (110 to 128 meters). The Fundy deep, south of Grand Manan Island at the mouth of the Bay of Fundy, is a basin some 27 miles long, with 100 to 112 fathoms (183 to 205 meters) and its deepest spot 165 fathoms (302 meters).

The two arms of the deep trough or basin of the gulf are separated by a roughly triangular area, with depths ranging generally from 70 to 90 fathoms (128 to 165 meters) but rising at its apex (roughly, in the center of the gulf) to within 4½ fathoms (8 meters) of the surface, as the dangerous, rocky shoal known as Cashes Ledge, the patch less than 30 fathoms (55 meters) deep being about 6 miles long in a southwest-northeast direction. Other offshore shoals in the gulf proper, which deserve mention here because I shall have occasion to refer to them later as landmarks, are as follows:

1. Stellwagen Bank, lying between Cape Cod and Cape Ann at the entrance to Massachusetts Bay, 9 to 20 fathoms (16 to 37 meters), with deeper channels north and south of it.

2. Jeffreys Ledge, a narrow ridge extending northeasterly from Cape Ann for about 45 miles, with depths less than 50 fathoms (91 meters), shoalest place 18 fathoms (33 meters).

3. Platts Bank, situated about 34 miles east-southeast from Cape Elizabeth, which rises to within 29 fathoms (53 meters) of the surface.

4. Jeffrey Bank, off Penobscot Bay, some 26 miles south of the outermost islet (Matinicus Rock), where there is a small area within the 50-fathom curve with a shallowest depth of 46 fathoms (84 meters).

5. Grand Manan Bank, a small shoal about 7 miles long lying about 18 miles south of Grand Manan Island; general depth 30 to 40 fathoms (55 to 73 meters).

6. Lurcher Shoal, a patch of broken, rocky bottom 1.5 to 20 fathoms (3 to 37 meters) deep, 15 miles off Yarmouth, Nova Scotia.

7. German Bank, a considerable but vaguely defined area west of Cape Sable, with depths of 30 to 35 fathoms (55 to 64 meters) bounding the debouchment of the Northern Channel into the basin of the gulf.

Mitchell (1881) has calculated that the mean depth of the gulf north of the sill, including its navigable bays and tributaries, is about 75 fathoms (137 meters).

The banks that form the southern sill of the gulf have been described frequently, and because of their importance in navigation their main features are summarized in the coast pilots issued by the British and United States Governments. The dimensions and area of Georges Bank, one of the most famous and productive fishing grounds in the North Atlantic, are mentioned above (p. 518). On the southern and eastern parts the depths range, in round numbers, from 30 to 40 fathoms (55 to 73 meters). Over its northwestern one-third the water is shallower, with a considerable but much broken area shallower than 20 fathoms (37 meters), culminating in the dangerous "Georges" and Cultivator Shoals, the former with only 2½ to 10 fathoms (4½ to 18 meters), the latter with 3 to 10 fathoms (6 to 18 meters). Both of these shoals break heavily in stormy weather, and both have proved graveyards for many fishing vessels. According to early rumor (Mitchell, 1881), Georges Shoal has been awash or even dry within historic times; but even as early as 1776 Hollingsworth decided that this tradition had no basis. It is worth noting that there is one well-marked sink situated on the northeast part of Georges Bank, centering at latitude 41° 59′ N., longitude 67° W. Prior to the spring of 1920 this was known (at least officially) from one sounding of 83 fathoms (152 meters) only, with neighboring depths of 30 to 40 fathoms (55 to 73 meters). On March 11 of that year the U. S. S. *Albatross* developed the region by a series of soundings, finding a maximum depth of 120 fathoms (220 meters) and an area of about 27 square miles deeper than 75 fathoms (about 140 meters).

Inside the 50-fathom (90-meter) contour Browns Bank is about 55 miles long from east to west, with an area about 700 square miles and a general depth of 30 to 50 fathoms.

Around most of the periphery of the basin of the gulf the slope is gradual, the 100-fathom (183-meter) curve lying about 12 miles from shore at its closest (off Cape Cod and about as near the outer islands in the northeast corner). The northern slope of Georges Bank is much more abrupt, falling from about 40 fathoms (73 meters) to 100 fathoms (183 meters) in a distance of only 3 to 5 miles.

The Gulf of Maine, with its southern sill, occupies the whole breadth of the Continental Shelf off northern New England and western Nova Scotia, with the south slopes of Georges and Browns Banks falling so steeply to the abyss of the North Atlantic that the zone between the 100 and 1,000 fathom contours (the "Continental Slope") is at one point (longitude about 66° W.) only 4 or 5 miles broad and not more than 20 miles anywhere abreast the mouth of the gulf between the longitudes of 65° and 71°.

WATERSHED

In more or less inclosed coastal seas, where the salinity of the water is influenced greatly by the amount of inflow from rivers and smaller streams, the extent of the watershed and amount of run-off of fresh water demand consideration. The land area tributary in this way to the Gulf of Maine includes something over one-third of the State of Massachusetts, two-thirds of New Hampshire, the entire State of Maine, half of the Province of New Brunswick, a small part of the Province of Quebec, and the northwestern and western coastal strips of Nova Scotia—altogether, in round numbers, some 61,300 square miles. No large rivers empty into the gulf south of Cape Ann; north of that point the chief tributaries, with their approximate drainage areas in square miles, are (1) the Merrimac, 4,553; (2) the Saco, 1,753; (3) the Presumpscot, 470; (4) the Androscoggin, 3,700; (5) the Kennebec, 6,330; (6) the Penobscot, 8,550; (7) the Machias, 800; (8) the St. Croix, 1,630; and (9), chief of all, the St. John, draining no less than 26,000 square miles. That is to say, the nine principal tributaries drain together over 53,000 square miles, or five-sixths of the total watershed.

TEMPERATURE

FEBRUARY AND MARCH

It is most convenient to begin the account of the temperature of the Gulf of Maine with the late winter and early spring, when the water has cooled to its minimum for the year and before vernal warming has proceeded to an appreciable degree.

No definite date can be set for this state because of regional and annual variations, but experience in 1913, 1920, and 1921 suggests that the lowest temperatures are to be expected over the gulf as a whole during the last week of February and first few days of March, except from Cape Sable out to the neighboring part of the basin, where the surface is coldest some weeks later, when the Nova Scotian current is flowing from the east past Cape Sable in greatest volume (p. 832). The temperatures recorded during the February–March cruise of 1920 may not have been the absolute minimum for that year, but the preceding winter had been so cold, with snowfall so heavy, that probably the open gulf is never more than fractionally colder than we then found it. The coastal belt may then be expected to chill below 2° at the surface all around the gulf by the end of winter (fig. 1), its central and offshore parts continuing slightly warmer (about 2.5° to 3.5°). In 1920 a surface tongue equally cold had also developed off southern Nova Scotia by the middle of March, spreading westward across Browns Bank but separated from the coast by slightly warmer (2.2° surface) water close to Shelburne. Present knowledge of the seasonal fluctuations of the Nova Scotian current (p. 832) also make it likely that some such development is to be expected yearly.

SURFACE

The surface temperature falls fractionally below 0° in Cape Cod Bay during winters when ice forms there in any amount. Thus in 1925, for example, the whole column of water in its central and eastern sides, in 12 to 34 meters depth, chilled to −0.4° to −0.7° by February 6 to 7, warming again to 1° to 2° by February 24. Passamaquoddy Bay chills to nearly as low a figure (0.77° at 20 meters, February 23, 1917; Willey, 1921).

If the winter of 1924–25 can be taken as typical (as seems fair, because rather a greater amount of ice formed in Cape Cod Bay than usual, although the air temperatures averaged warmer than normal and the snowfall less), a line from the tip of Cape Cod to Boston Harbor will bound this 0° water in the Massachusetts Bay region. Equally low temperatures no doubt prevail on the surface in the inner parts of the bays and among the islands along the coast of Maine in winters when much ice forms there.

By contrast it is not likely that the surface of the basin of the gulf, including the western part of the Bay of Fundy, ever cools below 2° at any season except for a brief period later in the spring (p. 681), when the surface in the eastern side may be chilled to 0° by the icy Nova Scotian current flowing past Cape Sable from the east. Minimum readings of 3° to 4° are to be expected over the southern side of the basin and on the eastern part of Georges Bank; 4° to 5° over its western half and off its southwestern slope.

An extreme range of about 5° surface temperature thus may be expected over the whole area of the gulf at the end of the winter, and a range of about 4° in its inner parts.

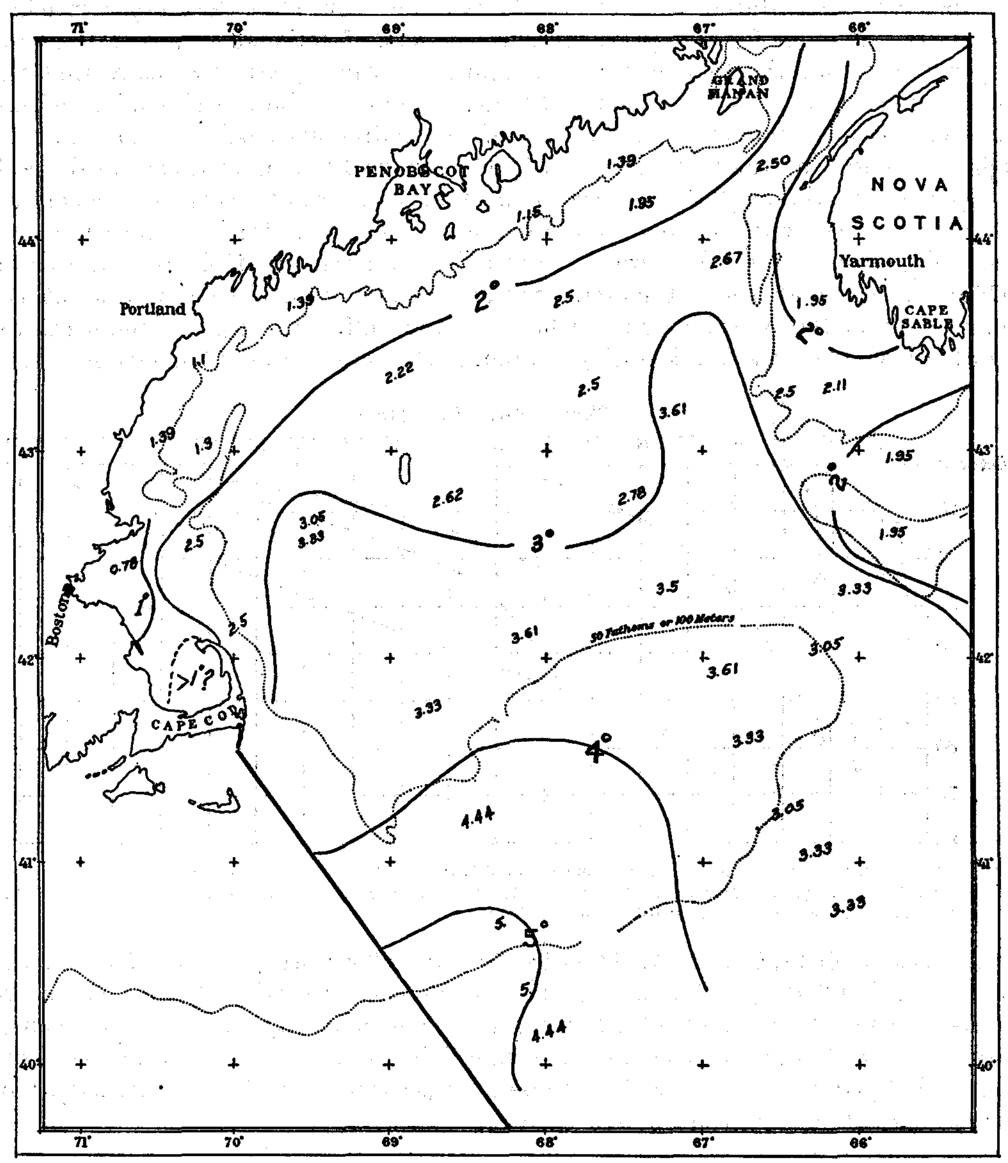

Fig. 1.—Temperature at the surface, February–March, 1920

VERTICAL DISTRIBUTION

At the end of the winter the temperature is very nearly uniform, vertically, down to a depth of 100 meters, rising slowly with increasing depth below that level. This state continues into March, until the climbing sun has warmed the surface appreciably. Whether the water is coldest immediately at the surface or 10 to 20 meters down at the end of February depends on the precise locality, on the state of the weather during the few days preceding, and, locally, on the stage of the tide, a question taken up in connection with the autumnal and winter cooling of Massachusetts Bay (p. 649). Our March cruise of 1920 began a few days after the temperature had passed its minimum for the year, the surface being fractionally warmer than the deeper water; but the temperature was still so nearly uniform vertically that the range was less than 1° in the upper 100 meters at most of the March stations within the outer banks (figs. 2 to 11). Most of the individual stations also showed a slight warming from the 20 to 40 meter level down to 100 meters, except in the sink off Gloucester (station 20050), where the bottom water was fractionally the coldest. Wherever the water was deeper than 100 meters a decided rise in temperature was recorded from that level downward. Thus the temperature off Cape Ann (station 20049) was 2.6° higher at 200 meters than at 100, and from 1° to 3° warmer at 175 meters than at 100 elsewhere in the basin of the gulf. The highest temperatures recorded inside Georges Bank during March, 1920, were at 150 to 250 meters, as follows: Station 20049, 5.66° to 5.63° at 180 to 200 meters; station 20053, 5.39° at 225 meters; station 20054, 5.4° to 5.48° at 175 to 250 meters; station 20055, 5.59° at 220 meters; station 20081, 5.39° at 200 meters. Thus, generally speaking, the deepest water of the gulf is the warmest and the superficial stratum the coldest at the beginning of the spring. A glance at the temperature sections (figs. 2 to 11) will show how widely this differs from the summer state.

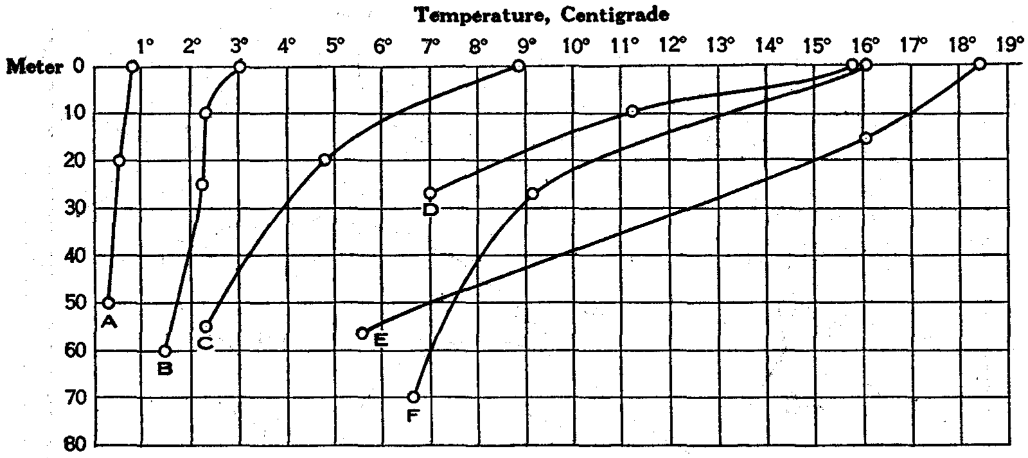

FIG. 2.—Vertical distribution of temperature in the inner part of Massachusetts Bay, March to August. A, March 8, 1920 (station 20062); B, April 6, 1920 (station 20089); C, May 16, 1920 (station 20123); D, August 23, 1922 (station 10632); E, August 23, 1922 (station 10640); F, August 20, 1915 (station 10106)

TEMPERATURE AT 40 METERS

It is probable that the narrow band of 0° to 1° water that skirts the whole coast line from Massachusetts Bay to the Grand Manan Channel on the 40-meter chart for February and March (fig. 12) reflects conditions as they existed at the surface a week or 10 days earlier in the season. Readings higher than 1° everywhere else, even after the unusually severe winter of 1920, make it seem unlikely that the offshore parts of the gulf ever chill below 1° at the 40-meter level. Temperatures of 1° to 2° at 40 to 50 meters in Massachusetts Bay early in February, 1925 (p. 658), contrasting with 0.4° on March 5, 1920 (station 20062), suggest that this stratum is about 1° warmer after a warm winter than after a cold one.

Rising temperature, passing offshore to 2° to 4° over the banks, with an abrupt transition to much higher values (9°) a few miles to seaward of the edge of the continent, is the most instructive general feature of this 40-meter chart. This, however, was complicated at the time by an expansion of water colder than that across the eastern end of Georges Bank from the neighboring part of the basin, alternating with a warm tongue that intruded inward along the Eastern Channel and a second area of cold (2°) water that reached Browns Bank from the eastward.[9]

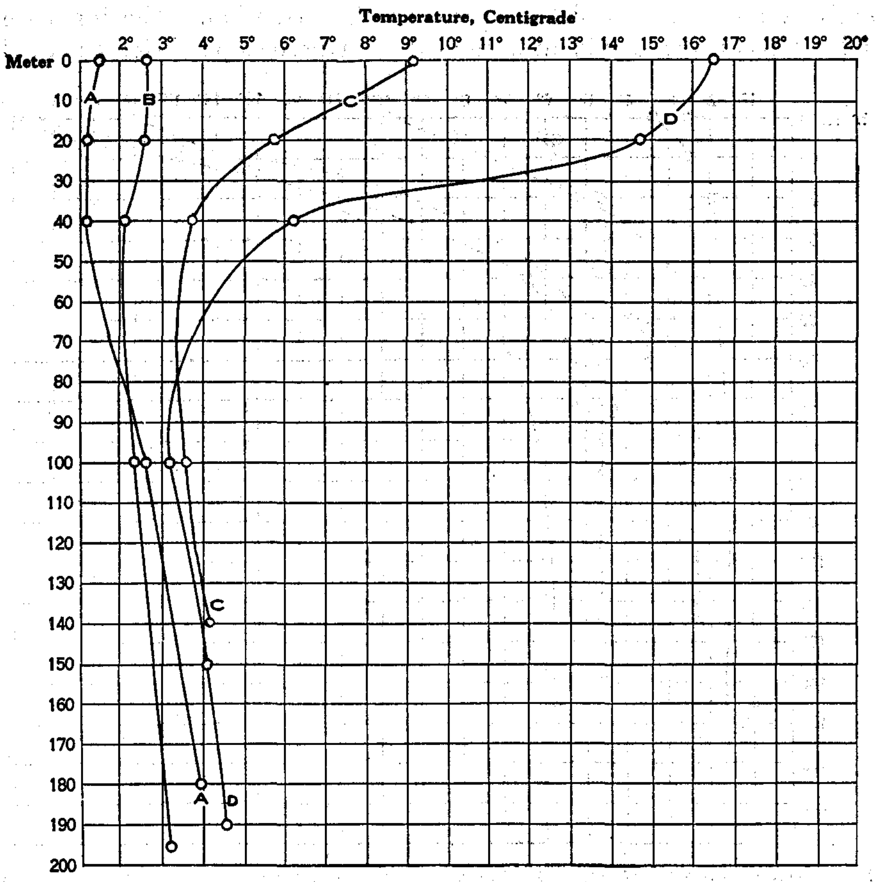

FIG. 3.—Vertical distribution of temperature off northern Cape Cod, March to July. A, March 24, 1920 (station 20088); B, April 18, 1920 (station 20116); C, May 16, 1920 (station 20125); D, July 19, 1914 (station 10214)

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[9] A profile run from Shelburne, Nova Scotia, to the edge of the continent in March (stations 20073 to 20077) affords a cross section of this.

TEMPERATURE AT 100 METERS AND DEEPER

In February and March, 1920, the entire basin of the gulf was warmer than 1.5° at 100 meters (fig. 13); all but its northwestern margin was warmer than 2°. The most noteworthy features of the chart for this level are the very striking contrast between the cold inner waters of the gulf (1° to 3°) and the high temperature (7° to 13°) outside the edge of the continent, with the clearly outlined tongue of comparatively warm (4° to 6°) water entering via the Eastern Channel (better defined at this level than at 40 meters) to extend northward and northwestward along the eastern branch of the trough, which deserves special attention. The influence of this warm indraft also is made evident around the northern slope of Georges Bank, westward to the Cape Cod slope, in readings of 3° to 3.6°. With this warm tongue as clearly defined by high salinity as it is by temperature, its nature as an actual current flowing into the gulf via the Eastern Channel from outside the continental edge is sufficiently established. Seldom, in fact, do the curves for salinity and for temperature correspond as closely as they do in this case, even to the pooling of the warm, saline water off the mouth of the Bay of Fundy. This phenomenon, of which we have had frequent evidence in other years and at other seasons, is discussed more

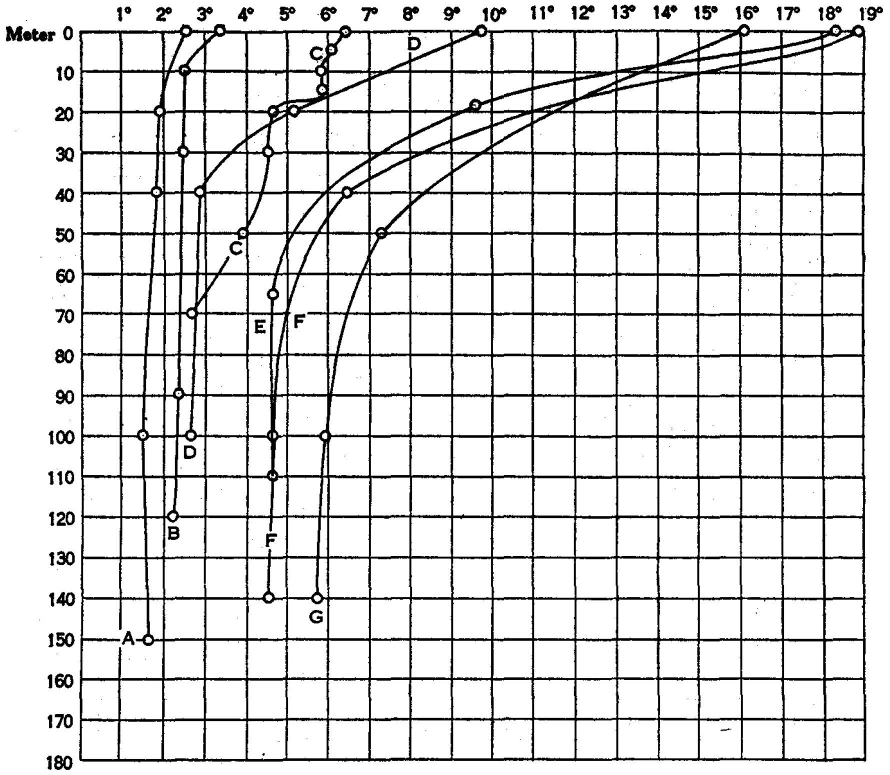

FIG. 4.—Vertical distribution of temperature at the mouth of Massachusetts Bay, March to August. A, March 1, 1920 (station 20050); B, April 9, 1920 (station 20090); C, May 4, 1920 (station 20120); D, May 16, 1920 (station 20124); E, July 20, 1912 (station 10002); F, August 22, 1914; G, August 31, 1915 (station 10306)

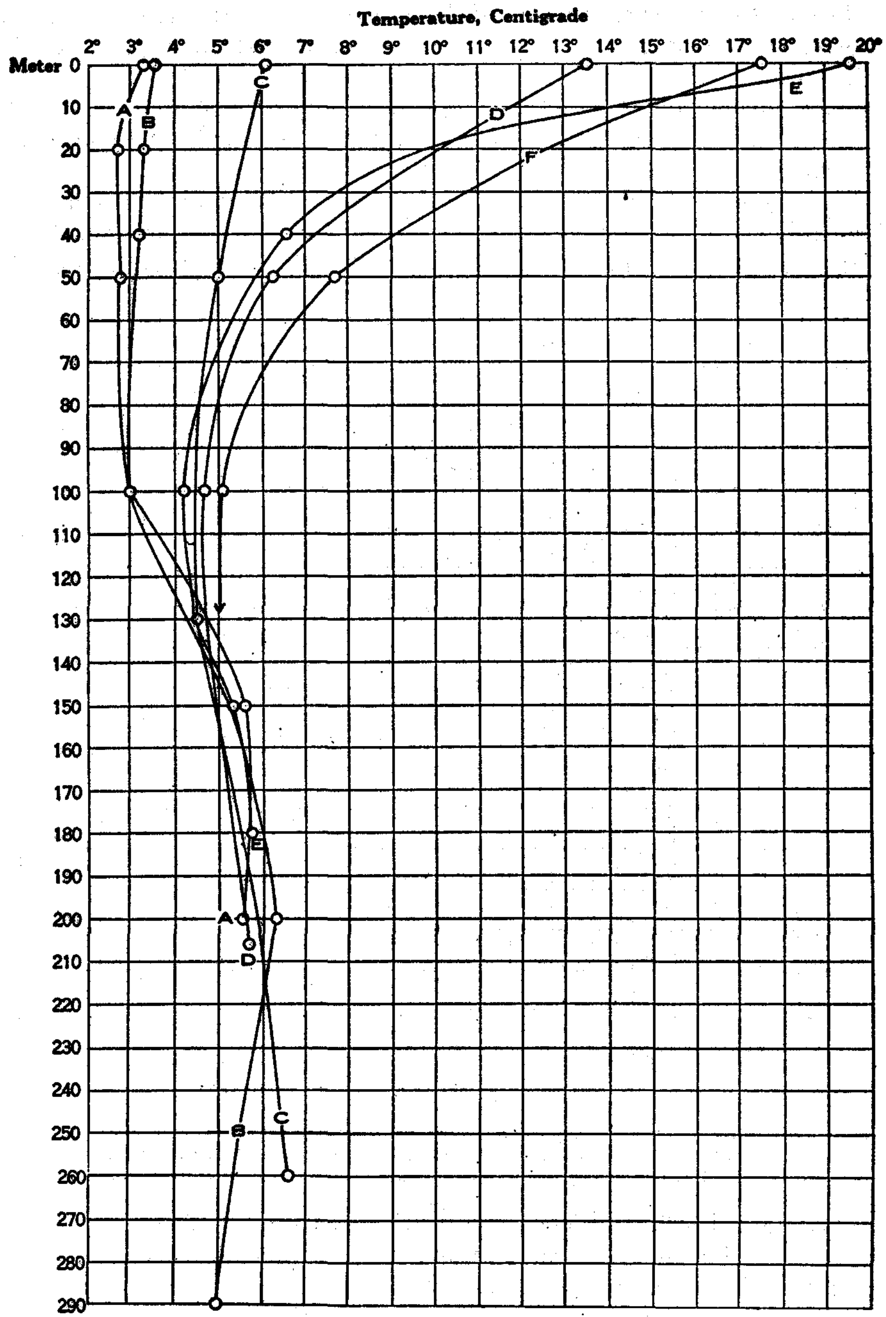

FIG. 5.—Vertical distribution of temperature in the western arm of the basin, off Cape Ann, March to August. A, February 23, 1920 (station 20049); B, April 18, 1920 (station 20115); C, May 4, 1915 (station 10267); D, June 26, 1915 (station 10299); E, August, 31, 1915 (station 10307)

fully in the chapter on the circulation of the gulf (p. 921). Its existence and its effect on the bottom temperatures of the gulf are among the most interesting facts brought out by the survey.

A counter expansion of water colder than 6° and fresher than 33 per mille, out of the gulf and around the southeast face of Georges Bank, also adds interest to the 100-meter chart.

In February and March, 1920, the gulf proved warmer at 200 meters than at 100. Probably the 200-meter level is never as cold as 4°; in fact, most of the readings were fractionally higher than 5°, being from 4.29° in the Fundy Deep to 6.85° in the Eastern Channel, with 5.2° to 5.6° at most of the stations. The 200-meter temperature at the three February-March stations outside the edge of the continent were as follows: 12.39° off the southwest face of Georges Bank on February 22 (station 20044), 5.9° off its southeast slope on March 12 (station 20069), and 7.89° off Shelburne, Nova Scotia, on March 19 (station 20077).

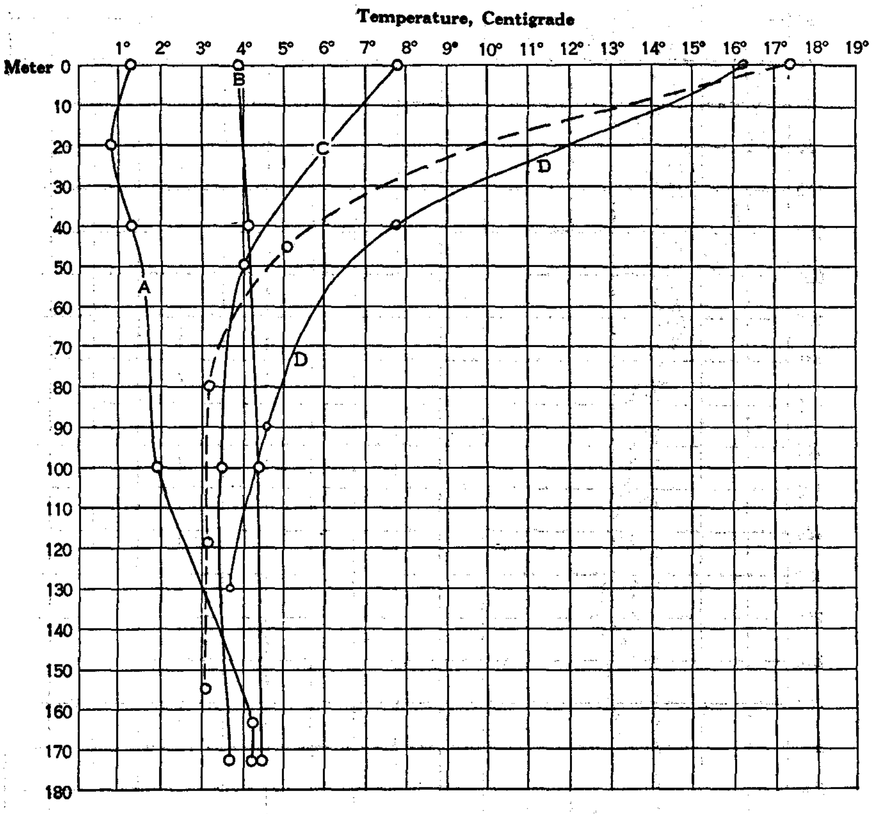

FIG. 6.—Vertical distribution of temperature in the deep trough between Jeffreys Ledge and the coast, March to August. A, March 5, 1920 (station 20061); B, March 5, 1921 (station 10509); C, May 14, 1914 (station 10278); D, August 22, 1914 (station 10252). The broken curve is for August 9 of the cold summer of 1923

PROFILES

Several profiles of the gulf are added, further to illustrate the distribution of temperature in March as exemplified by the year 1920. The first of these, running eastward from Massachusetts Bay to the neighborhood of Cape Sable (fig. 14), shows the spacial relationship between the comparatively high temperature (upward of 4°) in the bottom of the two arms of the basin, below about 120 to 160 meters, the banking up of 4° to 5° water in the eastern side just mentioned, and the colder (0° to 2°) water in the inner part of Massachusetts Bay in the one side of the gulf and along western Nova Scotia in the other. It also affords evidence more graphic than the charts that this warm bottom water, as it drifts in through the Eastern Channel, makes itself felt right up to the surface in the coldest season by temperatures about 1° higher than those either to the west or to the east of it. A much lower temperature in the bottom of the bowl off Gloucester (1.5° to 1.6°) than at equal depths in the neighboring basin (5°) deserves attention as evidence of the efficacy of its barrier rim. Because so protected by the contour of the bottom, the low temperatures of the preceding winter persist until much later in the season in the deeper levels of sinks of this type than in other parts of the open gulf.

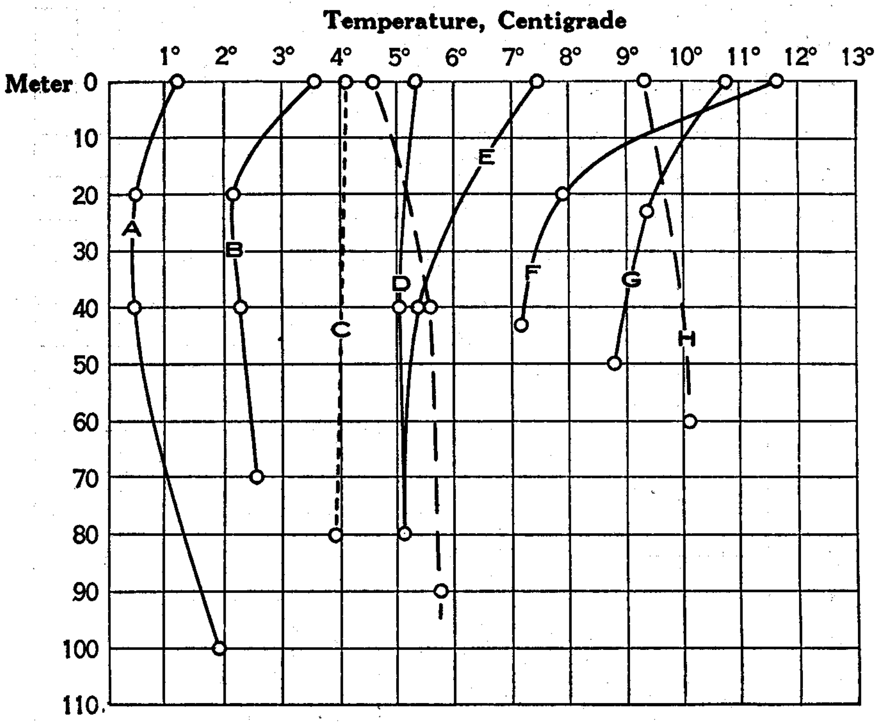

FIG. 7.—Vertical distribution of temperature near Mount Desert Island in various months. A, March 3, 1920 (station 20056); B, April 12, 1920 (station 20099); C, May 10, 1915 (station 10274); D, June 11, 1915 (station 10284); E, June 14, 1915 (station 10286); F, July 19, 1915 (station 10302); G, August 18, 1915 (station 10305); H, October 9, 1915 (station 10328); I, January 1, 1921 (station 10497)

The considerable stratum of water colder than 3° (1.89° to 2.76°) in the mid levels of the west-central part of the basin is made conspicuous on this profile by contrast with the warm core that splits it in the eastern side. Had the profile been run a few miles farther north, the contrast in temperature would have appeared still sharper in this relative region (at station 20054); less so a few miles farther south (at station 20053), as the charts for the surface and for the 40-meter level (figs. 1 and 12) make clear.

The most notable features of a profile running south from the offing of Cape Elizabeth, across Georges Bank and the continental slope (fig. 15), is its demonstration (*a*) that the transition in temperature from the boreal waters of the gulf, on the one hand, to the oceanic water outside the continental edge, on the other, is hardly less abrupt along this line in the last week of February and first week of March than it is in midsummer (p. 615); and (*b*) that the bottom at 75 to 300 meters was bathed by water as warm as 8° to 11° as far east as longitude 68° along the

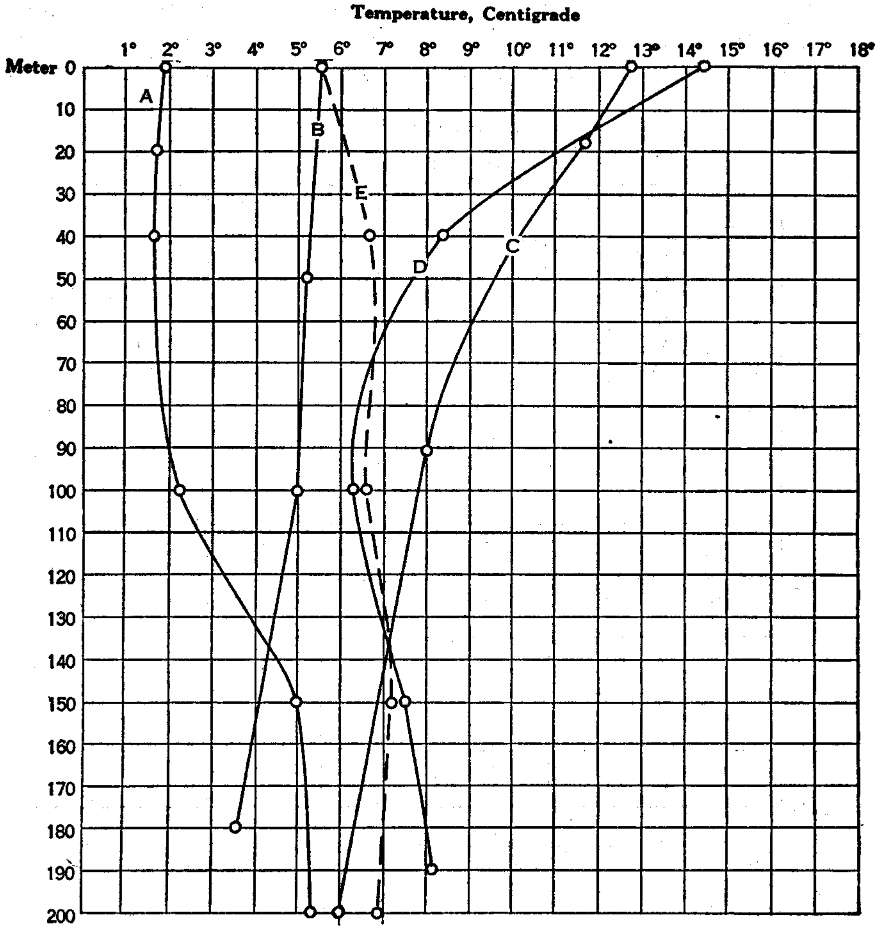

FIG. 8.—Vertical distribution of temperature in the northeastern corner of the Gulf of Maine. A, March 22, 1920 (station 20081); B, June 10, 1915 (station 10283); C, August 12, 1913 (station 10097); D, August 12, 1914 (station 10246); E (broken curve), January 5, 1921 (station 10502)

continental slope. Equally high bottom temperatures on the upper part of the slope in the latitude of Chesapeake Bay (station 20041), off Delaware Bay (station 20042), and off New York (station 20043), that same February, also off Chesapeake Bay in January, 1914 (Bigelow, 1917a, p. 60), make it likely that a warm band of this sort (often spoken of as the "inner edge of the Gulf Stream") touches the bottom along this depth zone throughout most winters. The March profile of the

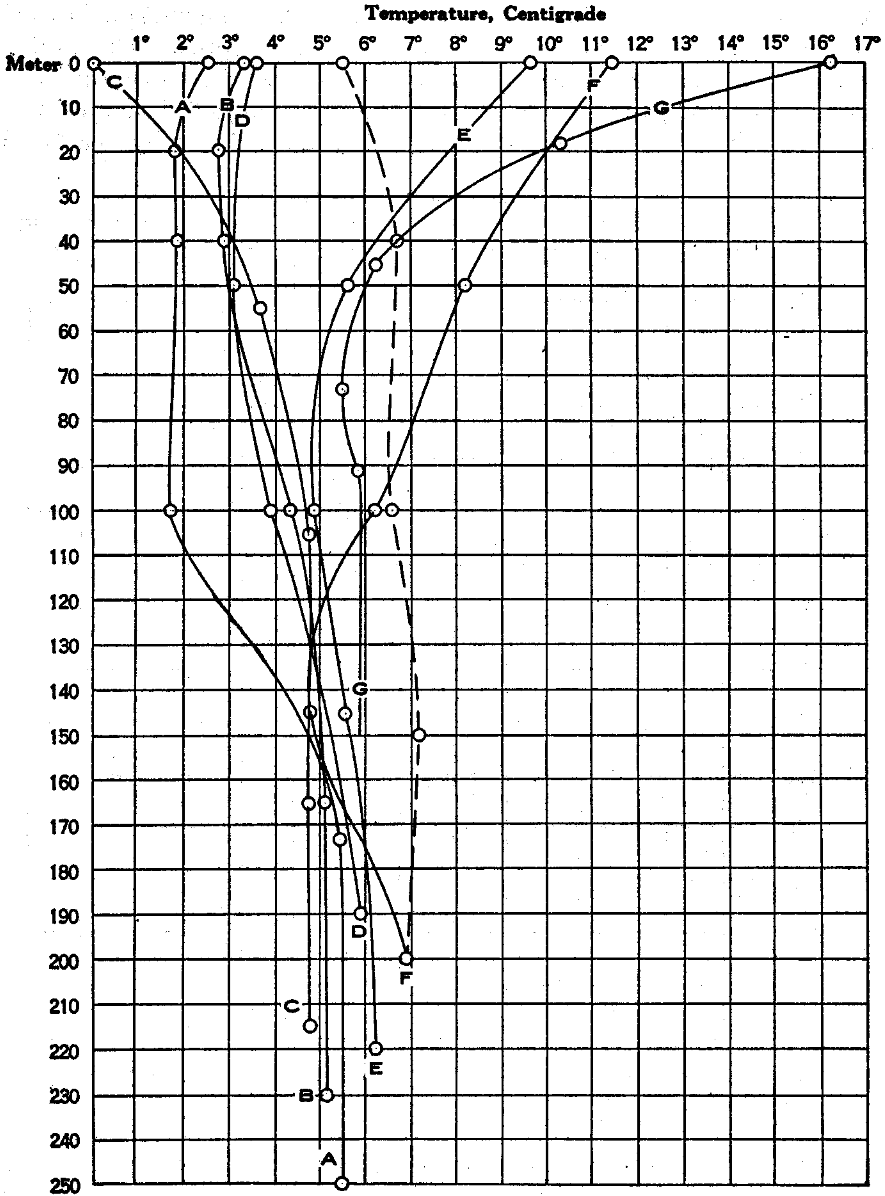

FIG. 9.—Vertical distribution of temperature in the eastern side of the basin of the Gulf of Maine. A, March 3, 1920 (station 20054); B, April 17, 1920 (station 20113); C, March 28, 1919 (Ice Patrol Station No. 3); D, May 6, 1915 (station 10270); E, June 19, 1915 (station 10286); F, August 7, 1915 (station 10304); G, September 1, 1915 (station 10309). The broken curve is for January 5, 1921 (station 10502)

eastern end of the bank (fig. 16), however, shows much less contrast in temperature between the two sides of the latter, with the oceanic water (warmer than 8° and salter than 34 per mille) so much farther out from the edge of the continent that even the outermost station (20069) did not touch it, leaving the bottom down the continental slope bathed with water colder than 5° at all depths. The profiles thus corroborate the temperature charts (figs. 12 and 13), to the effect that the warm bottom zone was obliterated somewhere between longitudes 67° and 68° W. (about midway the length of Georges Bank) in February and March by the "cold wall" that wedges in between the slope and the oceanic water. As it is the existence of this warm zone that permits the year-round existence of warm-water subtropical invertebrates and of the tilefish along this stretch, the definite location of its eastern limit is a matter of some biological importance. The contrast between the graph for our outermost station off the western end of Georges Bank and two other deep stations off its eastern end and off Shelburne, Nova Scotia (fig. 18), is an additional illustration of the sudden dislocations about midway of the bank, with a

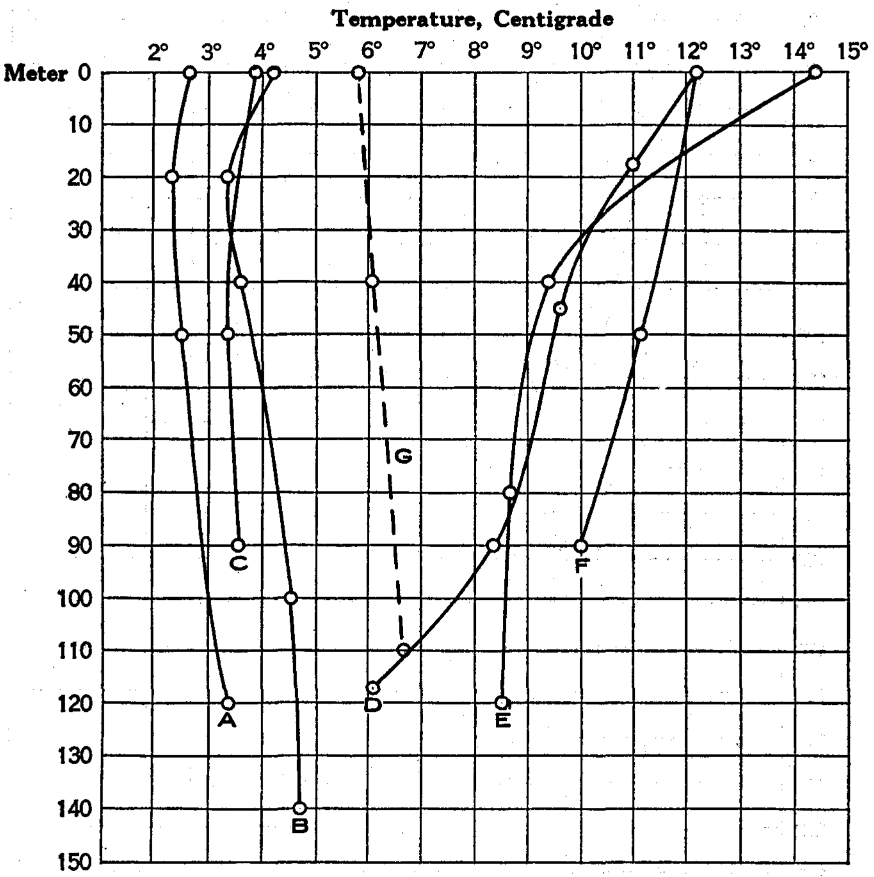

FIG. 10.—Vertical distribution of temperature near Lurcher Shoal in various months. A, March 23, 1920 (station 20082); B, April 12, 1920 (station 20101); C, May 10, 1915 (station 10272); D, August 12, 1913 (station 10096); F, August 12, 1914 (station 10245); G, January 4, 1921 (station 10500)

difference of about 5° to 6° between the two ends of the latter at all levels from 20 meters down to 300.

The fact that the two eastern stations (20069 and 20077) did not differ from each other by more than 2° in temperature at any depth is evidence that the cold wedge that they illustrate was itself nearly uniform in temperature for a considerable distance from west to east. The difference between station 20044, on the one hand, and stations 20069 and 20077, on the other, was greatest at the stratum where all three were warmest—100 to 200 meters. Below this, at depths greater than 300 meters, the curves for all three of these deep stations converge, the readings for all falling within a range of 0.5° at 1,000 meters (station 20044, 4.2°; station 20069, 3.77°; station 20077, 3.9°), approximately at the temperature that is typical of the abyssal waters of the North Atlantic as a whole and differing little from the readings obtained at corresponding depths and locations along the slope in summer between Nova Scotia and the latitude of Chesapeake Bay (p. 605; Bigelow, 1915, 1917, 1922).

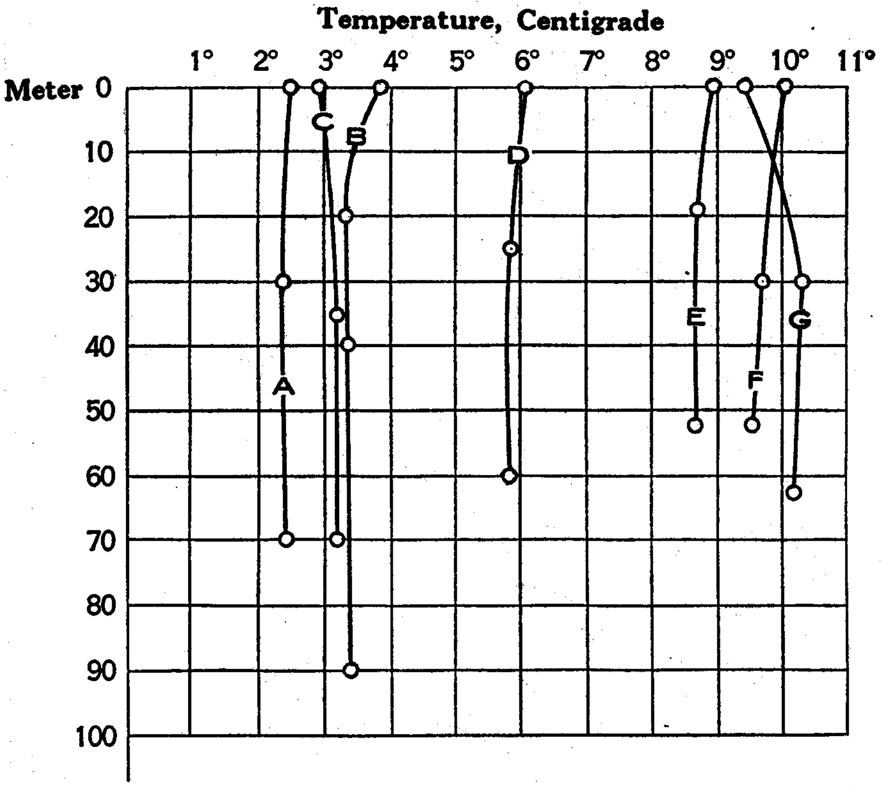

FIG. 11.—Vertical distribution of temperature on German Bank, March to September. A, March 23, 1920 (station 20085); B, April 15, 1920 (station 20103); C, May 7, 1915 (station 10271); D, June 19, 1915 (station 10290); E, August 12, 1913 (station 10095); F, August 12, 1914 (station 10244); G, September 2, 1915 (station 10311)

Unfortunately the data are not complete for the February station on the northern part of Georges Bank (20047), but it is probable (hence so designated on the profile) that 3° to 4° water was continuous right across the western end of the bank at the 10 to 30 meter level.

Our experience has been that the water is so actively mixed by tidal currents on the shoaler parts of Georges Bank that a complete equalization of temperature may be expected there locally at any season. Had the western profile (fig. 15) cut such a location, the readings would have been about 4° to 4.5° from surface to bottom; but with a difference of about 0.1 per mille of salinity between the surface and the bottom in 50 meters at station 20047 (p. 998), evidently such was not the case.

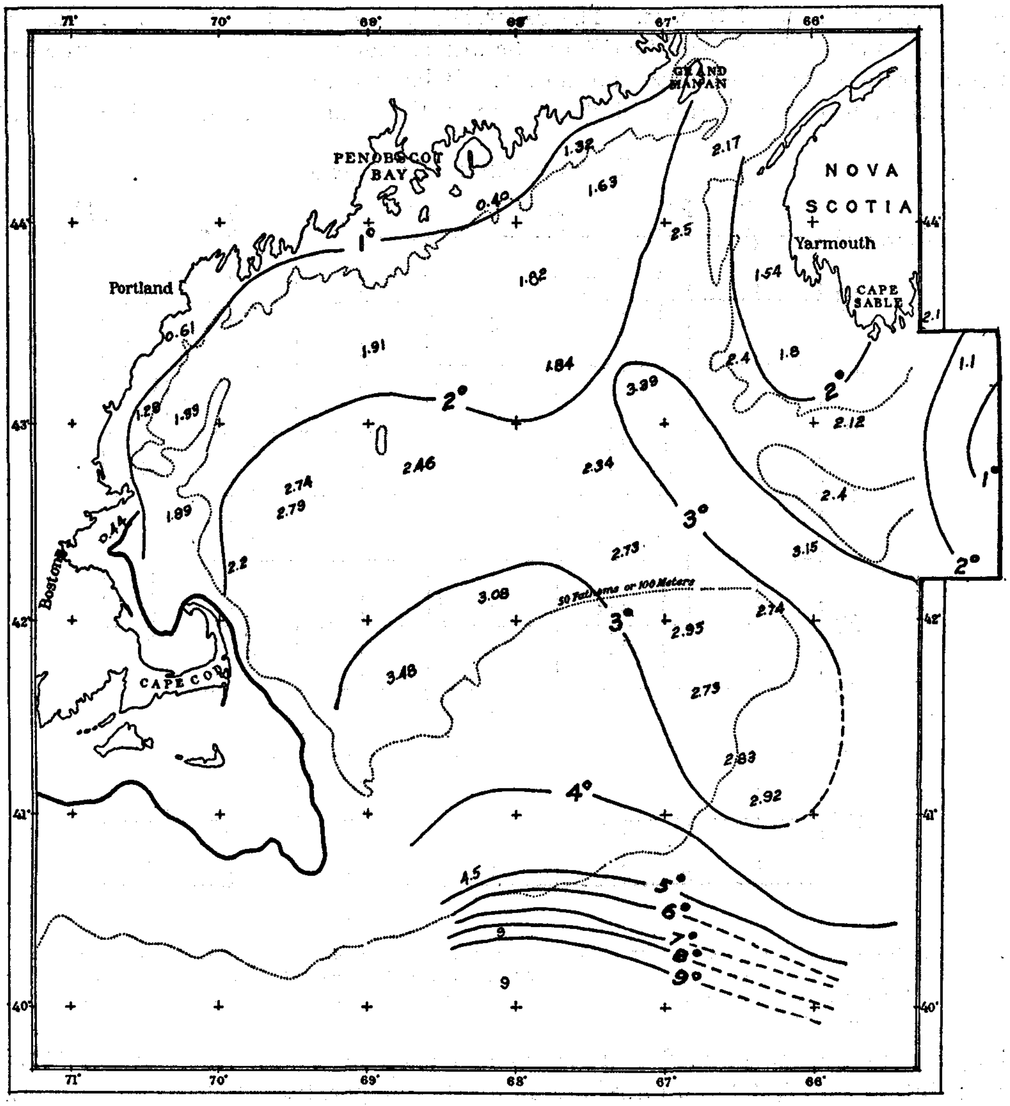

FIG. 12.—Temperature at a depth of 40 meters, Febuary-March, 1920

Only one other feature of this end of the profile calls for attention—the encroachment of water warmer than 7° on the southern side of Georges Bank and the abrupt transition in bottom temperature across the latter from north to south (4° to 12°).

The inner parts of the gulf at the coldest season are warmest (5° to 6°) at the bottom, coldest (2°) along shore and within 10 to 20 meters of the surface.

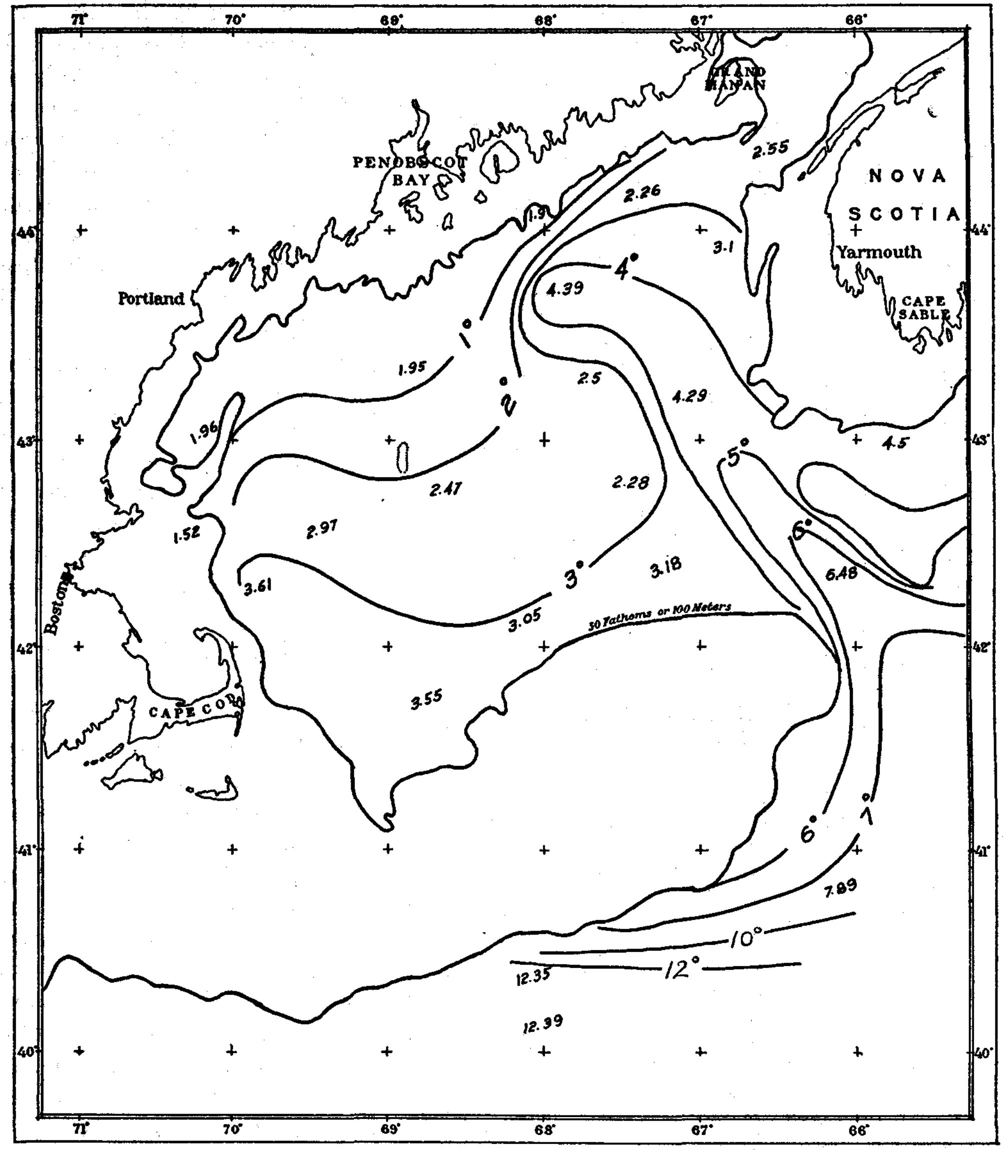

FIG. 13.—Temperature at a depth of 100 meters, Febuary-March, 1920

The wedge-shaped contour of this coldest water (3°), projecting shelflike over the basin, with slightly higher temperatures above it as well as below (fig. 15), taken by itself might suggest some overflow by warmer surface water from the south. The vertical uniformity of salinity in the upper stratum (p. 705), however, favors

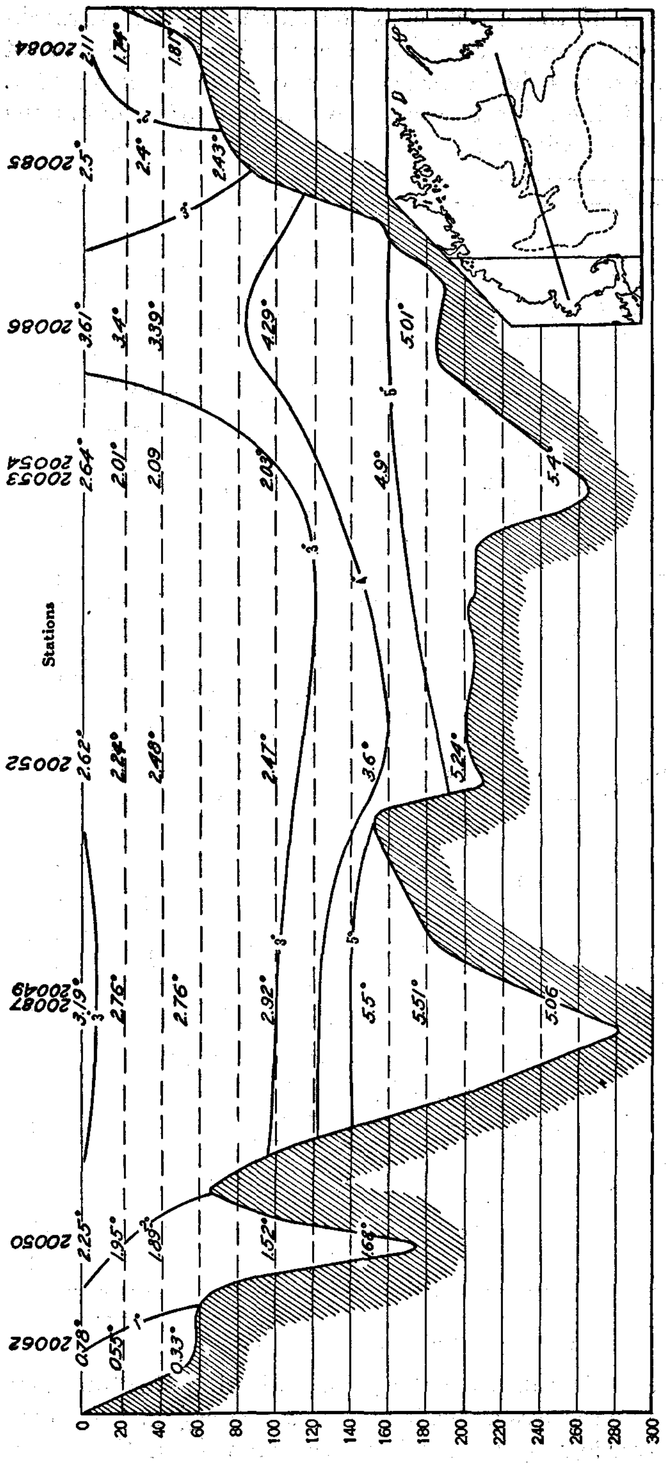

FIG. 14.—Temperature profile crossing the gulf from Massachusetts Bay to the vicinity of Cape Sable, March 5 to 23, 1920

the simpler explanation that temperatures slightly higher at the surface than a few meters down merely reflect the first stage in the vernal warming by the sun, which proceeds throughout the spring months. Probably the upper 10 meters would have been found homogeneous in temperature in the coastal zone, or the surface slightly the coldest level then, had the profile been run two weeks earlier in the season.

The increase of temperature from the shore seaward is again illustrated on the corresponding profile of the eastern side of the gulf (fig. 16). In this case, however, the courses of the isotherms are complicated by the fact that this particular profile cuts the westward extension of the warm core that enters the gulf via the Eastern Channel (pp. 526 and 529). Consequently, the profile shows the curves for 2, 3, 4, and 5 degrees, rising considerably nearer to the surface over the northern slope of the basin (station 20055) than closer inshore, on the one hand (station 20056), or in the deeper water of the basin, on the other (station 20054), indenting the cold (1° to 2°) surface layer from belo . Readings taken at a depth of 40 to 50 meters

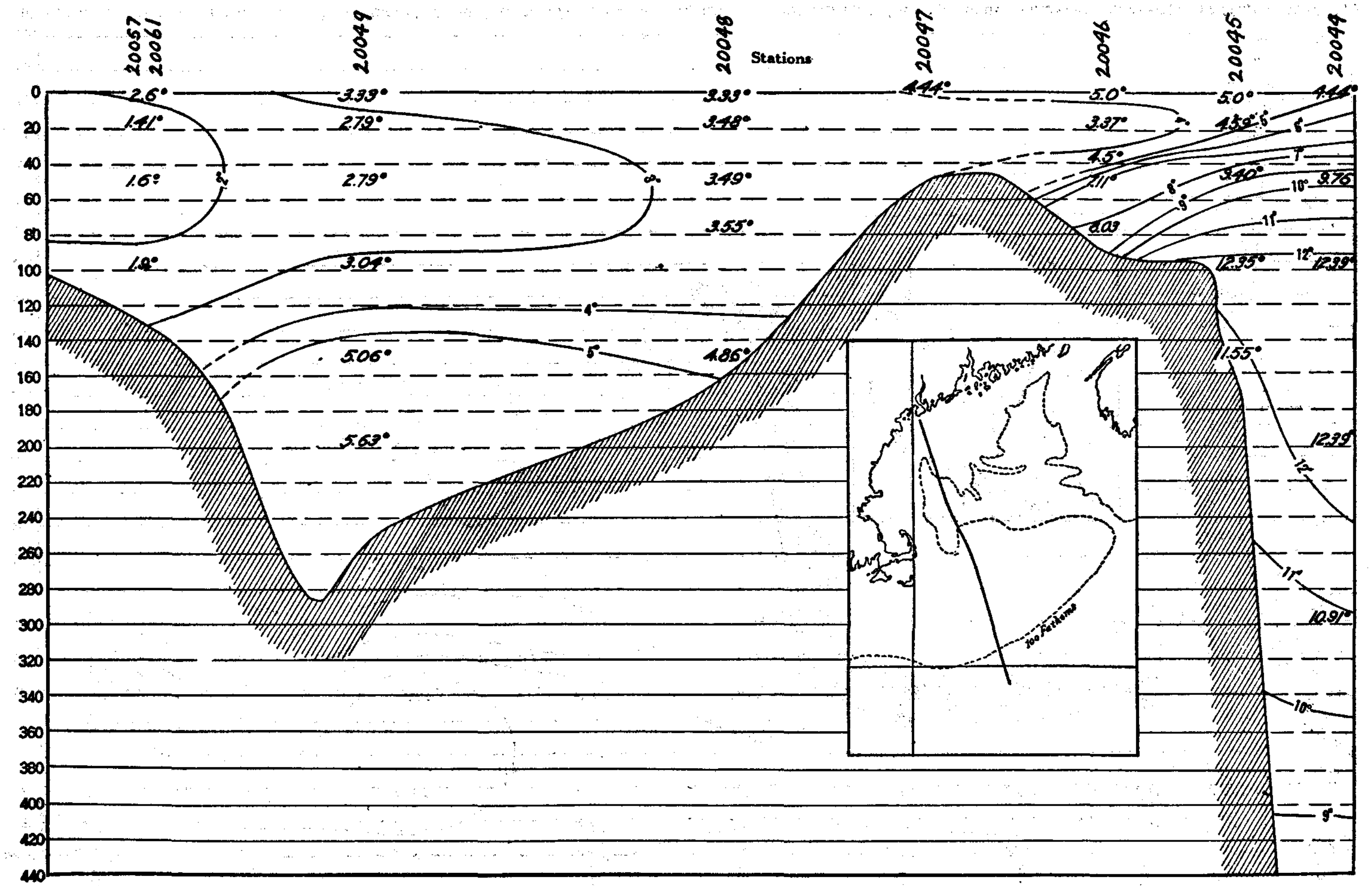

FIG. 15.—Temperature profile running southeasterly from the northwestern part of the gulf, off Cape Elizabeth, across Georges Bank to the continental slope, February 22 to March 4, 1920

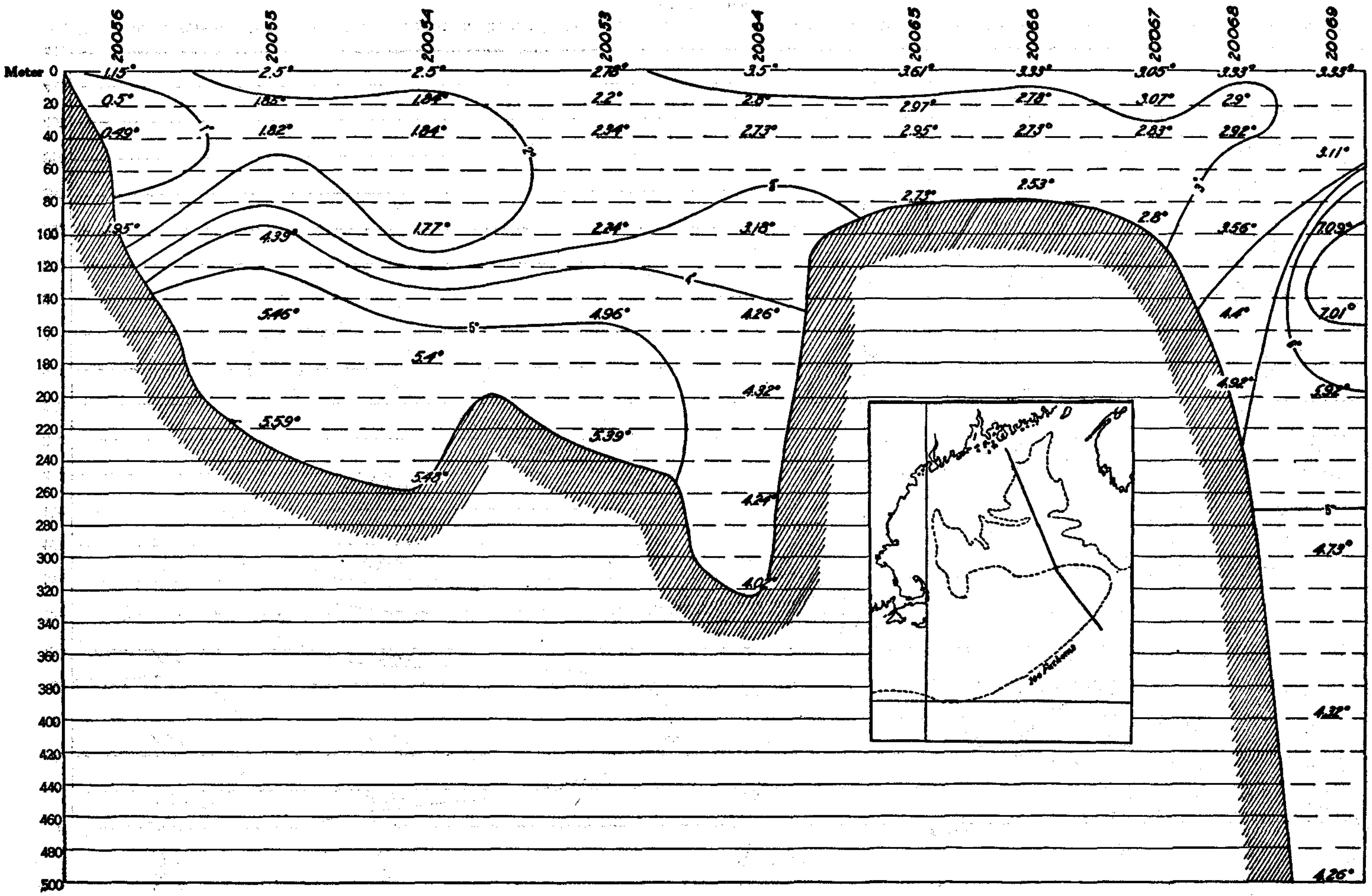

FIG. 16.—Temperature profile running from the vicinity of Mount Desert Island, southeasterly across the eastern part of Georges Bank to the continental slope, for March 3 to 12, 1920

along the axis of this cold stratum then rose fairly uniformly from about 0.5° close to land to from 2.4° to 2.7° in the southern side of the basin, to 2.7° to 2.9° over Georges Bank, and to 3.1° over the continental slope, as just described. On the other hand, the water as warm as 5° that floods the greater part of the basin at depths greater than 120 to 150 meters did not then touch the northern slope of Georges Bank, off which the water was fractionally colder than 5° right down into the deepest fold of the trough (station 20064).

The fact that the southern end of this profile crossed one of the chief breeding grounds for haddock in North American waters, and at the height of the spawning season, lends biological interest to the temperatures at stations 20061 to 20068. Evidently the eggs were being set free in water of about 2.5° to 2.7°.

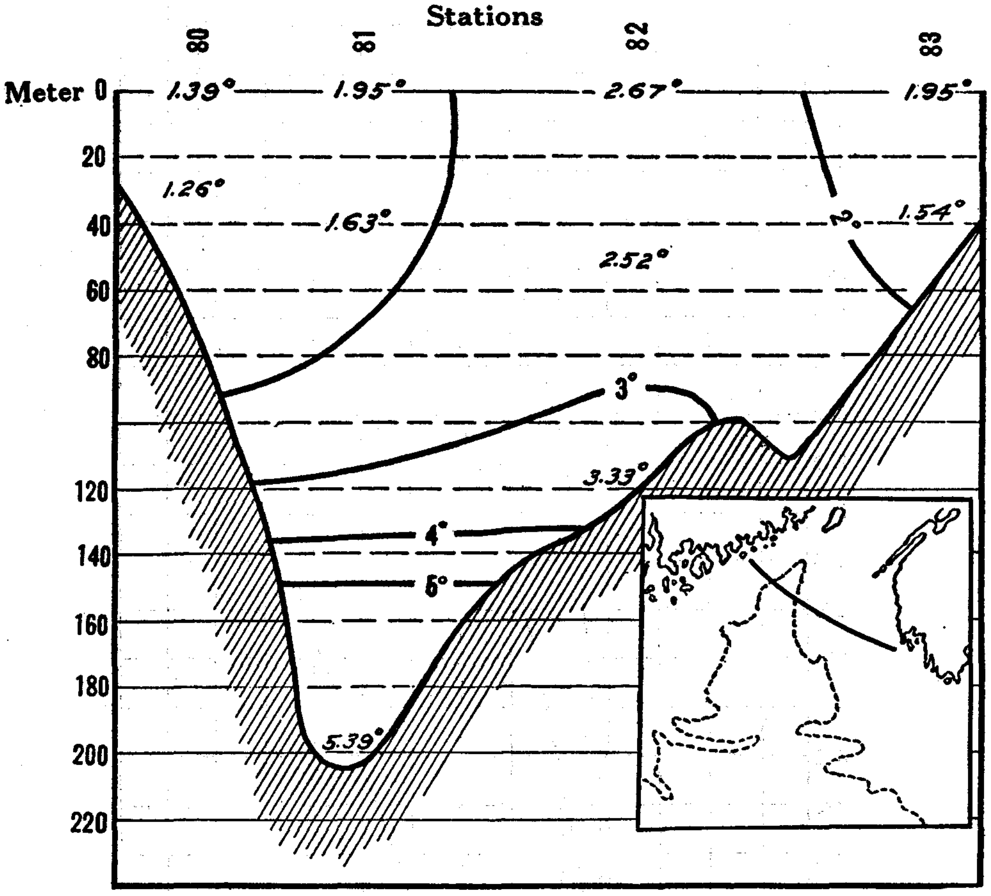

FIG. 17.—Temperature profile crossing the northeastern part of the gulf, off the mouth of the Bay of Fundy, for March 22 and 23, 1920 (stations 20080 to 20083)

The boundaries of the comparatively warm (5°) bottom water in the eastern arm of the basin, for March, are outlined further by a profile from Maine to Nova Scotia, opposite the mouth of the Bay of Fundy (fig. 17, stations 20080 to 20083). Temperatures higher than 5° were confined to depths greater than 150 meters along this line, but the isotherm for 3° shows the warmer bottom water banking up against the

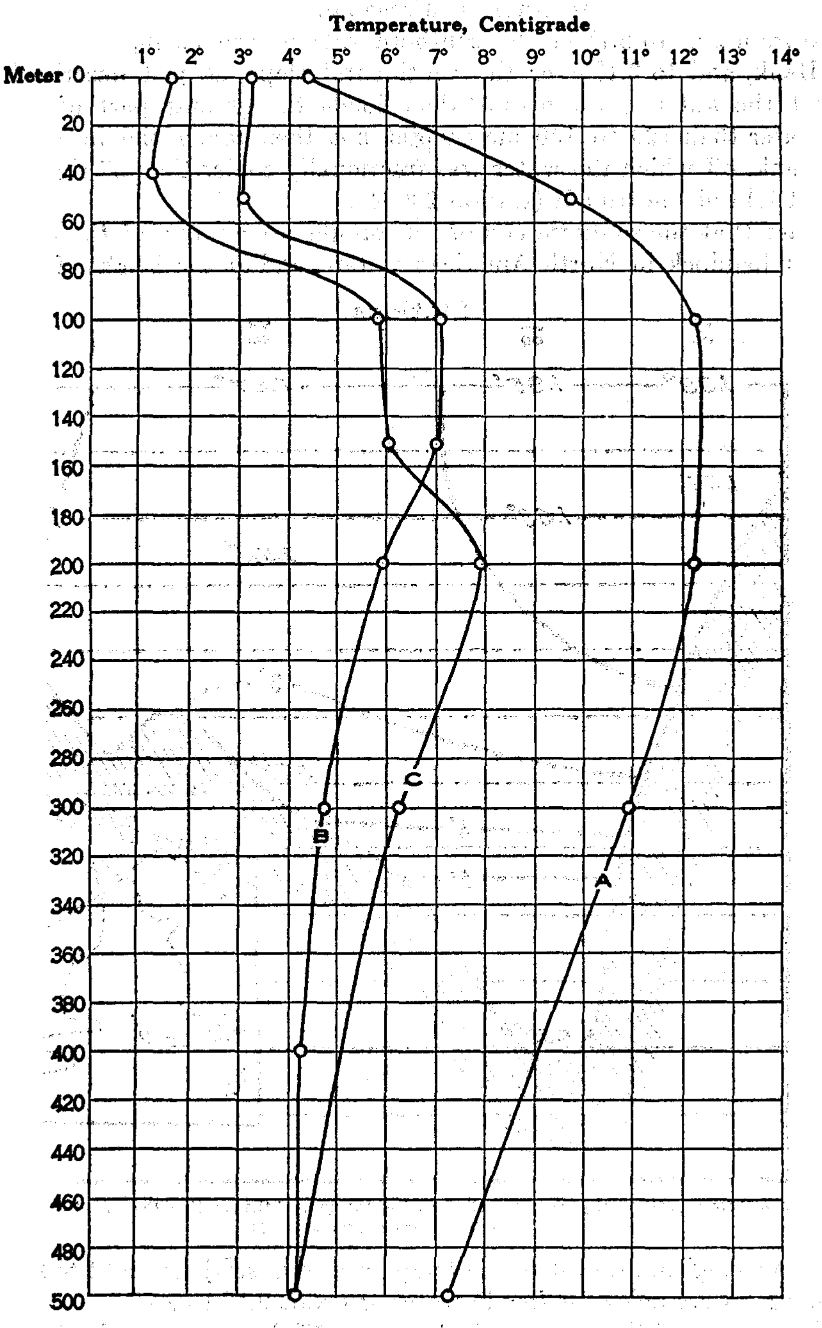

FIG. 18.—Vertical distribution of temperature along the continental slope. A, off the western part of Georges Bank (station 20044); B, off the eastern end of Georges Bank (station 20069); C, off Shelburne, Nova Scotia (station 20077), February-March, 1920.

eastern slope of the gulf (against the right-hand side for an entrant current) to within 90 meters of the surface in the manner with which cruises at other times of year have made us familiar (p. 619). Temperatures are slightly lower in the shore ends of this profile, as is usual for the cold season. Failure to obtain readings lower than 1° may be explained on the assumption that solar warming is propagated downward to a greater depth off Maine and off Nova Scotia by the strong tides of those localities during the first three weeks of March, than in the western side of the gulf, where tidal stirring is less active.

The relationship existing in March between the cold waters over Georges and Browns Banks and in the Northern Channel, on the one hand, and the warm indraft into the Eastern Channel, on the other, is illustrated by a profile following the arc of the banks (fig 19) Bottom water of 6° to 7° in the Eastern Channel, banked up like a ridge along its trough (isotherms for 3° to 6°), contrasts with 3° to 4.5° at equal depths in the Northern Channel, where temperatures higher than 4° were confined to a thin bottom layer deeper than 110 meters (station 20048). A bottom temperature fractionally higher than 3° on Browns Bank points to some tendency for the warm water that drifts in through the Eastern Channel to overflow the eastern rim of the latter; but the March data show that this circulatory movement was limited to depths greater than 70 meters. Probably the fact that the readings on Georges Bank showed no sign of any encroachment of the warm water in that direction, which is corroborated by salinity (p. 719), is due to the deflective effect of the earth's rotation, deflecting the current to the right (p. 849). Other features of the profile that claim attention are the uniformity of temperature over the eastern part of Georges Bank from east to west; the fact that the surface was fractionally warmer than the 20-meter level there and over the Eastern Channel (a first sign of vernal

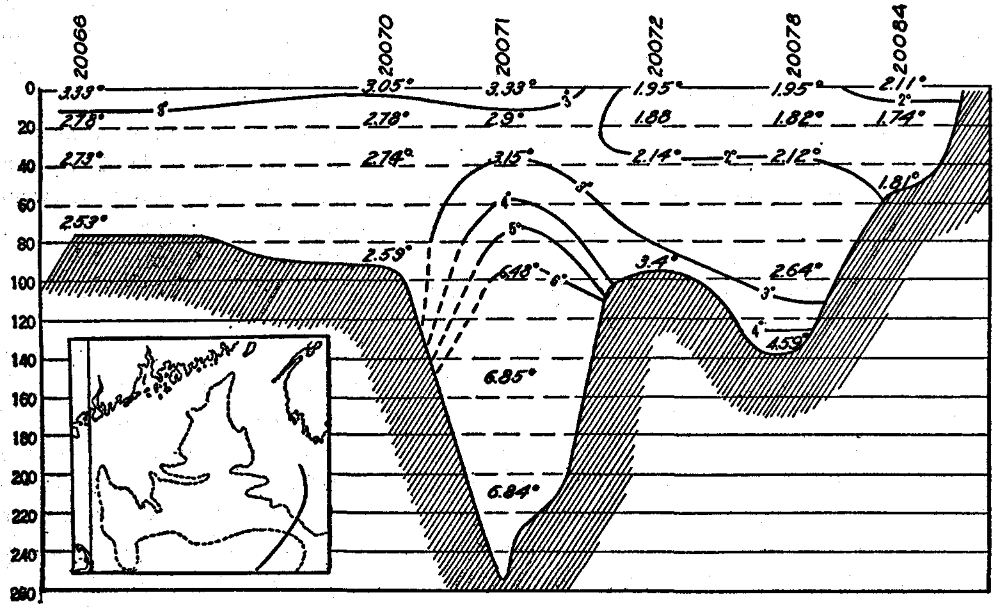

FIG. 19.—Temperature profile running from the eastern part of Georges Bank, across the Eastern Channel, Brown's Bank, and the Northern Channel, March 11 to 23, 1920

warming); and that while the inshore (Cape Sable) end of the profile was coldest as is usual at this season, the temperature was fractionally higher close in to the land near the cape than a short distance out at sea. A differential of this same sort would have been more apparent had the profile been located a few miles farther east, because the whole column in 75 meters depth, close in to Shelburne (station 20073), was fractionally warmer than 2° (p. 1000), while the water farther out on the shelf (stations 20074 and 20075) was colder.

BOTTOM

The temperature of the bottom water, in depths greater than 200 meters, varied in March from 4.02° off the northern slope of Georges Bank in 330 meters (station 20064) to 6.84° in the Eastern Channel in 215 meters (station 20071), with readings of 5.06° to 5.59° at depths of 225 to 250 meters elsewhere in the basin. It is interesting to find the deepest water coldest just north of Georges Bank at the location just mentioned, for this was also the case at 200 meters; whereas the northern side of the basin, not the southern, was the coldest at 100 meters.

For the biologist, the bottom temperature of the gulf at the coldest season is interesting as evidence of the greatest cold that bottom-dwelling animals of any sort must endure in various regions. In general, a parallelism then obtains between temperature and depth, the bottom being warmer the deeper the water. This relationship is complicated, however, by the increase in temperature from the shore seaward (p. 525), independent of depth, illustrated by the charts for the 40-meter and 100-meter levels (figs. 12 and 13.)

With more or less ice forming every winter in shoal bays and among the islands, the littoral zone is chilled from time to time to the freezing point of salt water in such situations. In Cape Cod Bay the *Fish Hawk* had a reading as low as −1.5° in 17 meters and −0.4° on the bottom in 34 meters on February 6, 1925 (cruise 6, station 6a, p. 1005); and while these readings are the lowest so far recorded for the open gulf, the data for that year and for station 20062 show that in Massachusetts Bay generally the bottom may be expected to chill to about 0° out to about the 30 to 40 meter level at some time during most winters, perhaps every year. No doubt this applies equally to the bays along the coast of Maine and to the tributaries of the Bay of Fundy; but along the open northern shores of the gulf, where strong tides produce an interchange of water more active than in Massachusetts Bay, it is not likely that the bottom temperature ever falls as low as 0° except within the littoral zone. Our two March stations (20083 and 20084) similarly show the bottom slightly warmer at 50 meters along western Nova Scotia at that season than in Massachusetts Bay; but later in the spring, when the icy Nova Scotian water from the east is flowing in greatest volume past Cape Sable, the bottom of the eastern side of the gulf may also be chilled to 1° - 0° down to a depth of 50 meters—perhaps still deeper, for a brief period, in some years. On the other hand, it seems that the bottom temperature of the deep troughs of the gulf never falls below 4°, except, perhaps, in very exceptional years.

Thus, any animal dwelling on bottom in the inner part of Cape Cod Bay, or anywhere among the islands of the coastal zone shoaler than 40 to 50 meters, is apt to be subjected to a temperature close to zero or lower at the end of winter. There is no danger of temperatures lower than about 1.5° to 2°, however, either on the slopes of the basin or in any one of the deep isolated bowls at depths of 100 meters or more, nor of temperatures lower than 4° on the bottom of the basin. A corresponding difference in the upper strata also may explain the disappearance of sundry planktonic animals from the coastal zone in winter, though they occur the year around in the gulf out at sea (Bigelow, 1926).

The contour of this mass of comparatively warm bottom water in the deeps of the gulf is graphically illustrated by a chart showing the isothermobath for 4° in February and March (fig. 20), for wherever temperatures as high as this were recorded within the gulf the underlying strata were still warmer. In 1920 (probably this applies yearly) there was no water as warm as 4° at this season at any level in the coastal zone, out to the 100-meter contour, on either side of the gulf. However (without attempting to draw too close a parallel between the intricate contour of the bottom and the temperature), the floor of the whole gulf at depths greater than 150 meters was bathed with water warmer than 4°, filling the whole basin below a uniform level of 120 to 130 meters in the western side and rising to within 60 to 80 meters of the surface in the eastern, as a well-defined ridge extending northward from the Eastern Channel, with a tendency to pool off the mouth of the Bay of Fundy.

It is not likely that this warm water ever overflows Browns Bank or the eastern half of Georges at that season, although not barred from them by the contour of the bottom. Certainly it did not in March, 1920; but the whole column of water over the western half of Georges Bank was then warmer than 4°, so that the chart (fig. 20) shows the isothermobath in question as rising to the surface there and dipping steeply toward the basin to the northwest. A contrast of 5° to 6° in bottom temperatures between the southwestern and southeastern parts of the bank (station 20046, 8°; station 20067, 2.8°) illustrates the wide differences in the physical conditions to which animals living on bottom are subject in winter and early spring on various parts of the bank.

It seems that at this season the fauna of the so-called "warm zone," which characterizes the upper part of the continental slope off southern New England and farther west (p. 531), must meet its eastern boundary at about longitude 67°, because the bottom temperature was only 4.9° at 190 meters off the southeastern face of Georges Bank on March 12 (station 20068), contrasting with 11.55° at a depth of 120 meters off its southwestern slope on February 22 (station 20045).

ANNUAL VARIATIONS IN TEMPERATURE IN EARLY SPRING

Slight variations are to be expected, of course, in the temperature of the gulf from one winter and spring to the next, even in what we may roughly term "normal" years; still more so between the exceptionally cold and warm winters that no doubt fall at intervals. The station data for 1920 and 1921 allow a thermal comparison for the northwestern parts of the gulf for early March of those years, amplified by the *Fish Hawk* survey of Massachusetts and Ipswich Bays in 1925 and by readings taken at a few localities in 1913.

At the head of Massachusetts Bay, off Boston Harbor, the readings for early March, 1921, and for February 24, 1925, are from 1° to 2° higher at all levels than those for 1290, although the dates were within a few days of one another. As the observations were made so soon after the coldest time of year that the temperature had not risen more than fractionally, it seems safe to say that the water did not cool below 1.5° to 2° in the northern half of the bay during the winters of 1921 or 1925, except right along the land, where it is most subject to winter chilling instead of close to 0°, as in 1920.

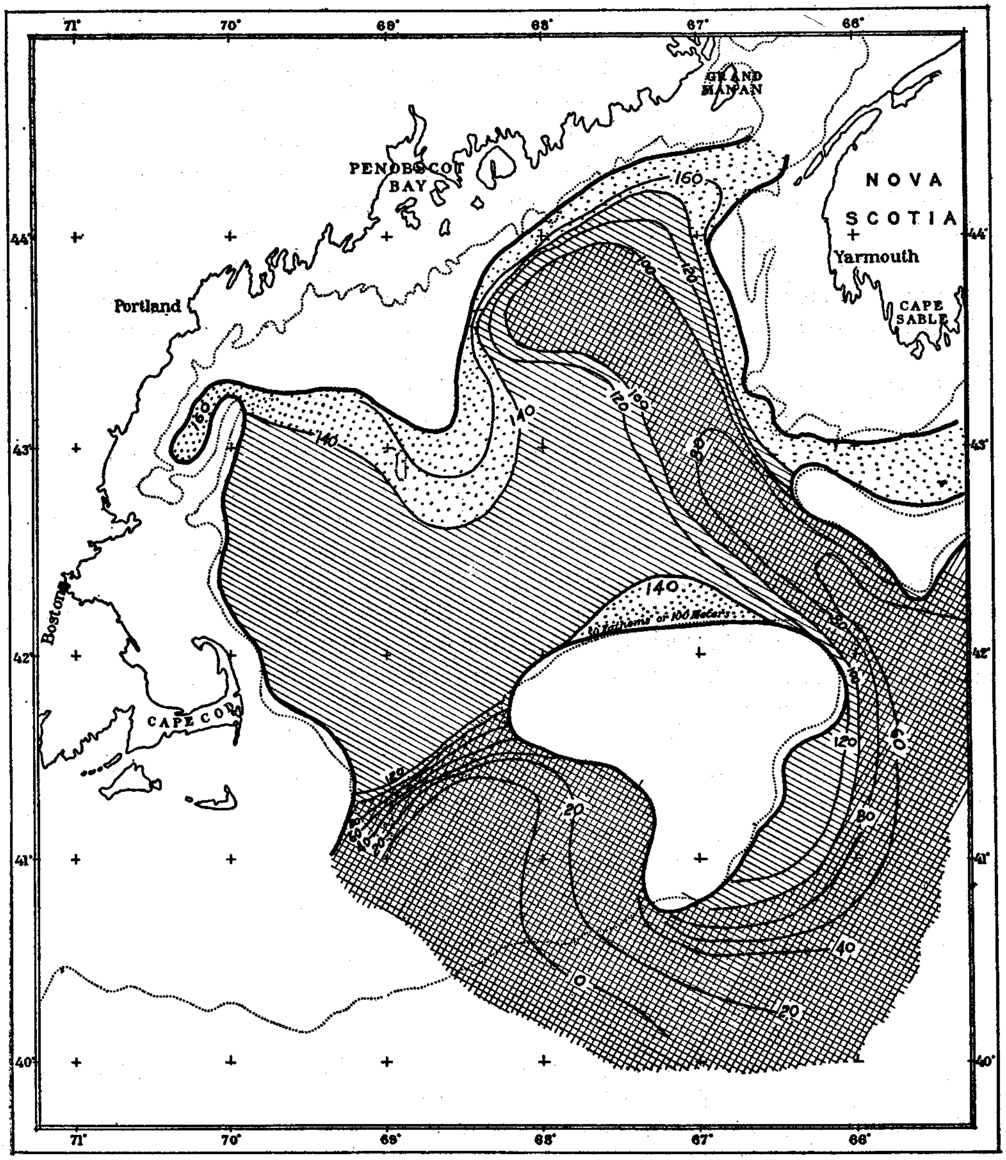

FIG. 20.—Depth below the surface of the isothermobath for 4°, February-March, 1920

A similar relationship obtained between the years 1920 and 1921 at the mouth of the Bay off Gloucester (fig. 21), the following readings taken there in the first week of March pointing to a minimum of 1.5° to 2° for the winter of 1920 and about 3° for 1921.

Meters	Mar. 1, 1920, station 20050	Mar. 5, 1921, station 10511	Meters	Mar. 1, 1920, station 20050	Mar. 5, 1921, station 10511
	Degrees	*Degrees*		*Degrees*	*Degrees*
0	2.5	3.61	100	1.52	3.85
20	1.95		150	1.68	3.86
40	1.89	3.84			

The winter of 1913 (Bigelow, 1914a, p. 391) was intermediate between 1920 and 1921 in temperature at this locality, with readings of 2.83° on the surface and 3.11° on bottom in 82 meters at a near-by location on February 13 (station 10053), when the minimum temperature for the winter was recorded.

An equally interesting annual difference is that the temperatures of late February and early March were lowest at the surface in 1913 and 1921, whereas in 1920 vernal warming already had raised the temperature of the surface fractionally above that of the underlying water by March 4. On February 24 to 28, 1925, the bottom was fractionally the warmest level at one deep station (*Fish Hawk* station 18a), while the surface was warmest at another (station 2), with the mid-stratum fractionally the coldest at both. Thus, the date at which the vernal warming of the surface begins to be appreciable does not necessarily mirror the state of the preceding winter, whether a cold one or a warm one in this part of the gulf (1920 was a very cold winter), but depends more on the degree of cloudiness, the precise condition of air, the direction of the wind, the temperature of the air, and on the snowfall from the middle of February on.

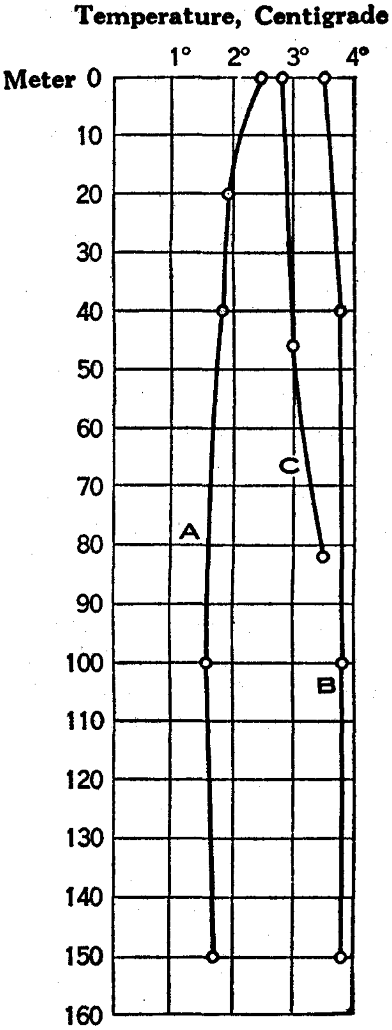

FIG. 21.—Vertical distribution of temperature off Gloucester during the first week of March of the years 1913, 1920, and 1921, to show the annual variation. A, March 1, 1920 (station 20050); B, March 5, 1921 (station 10511); C, March 4, 1913 (station 10054)

Turning now to the coastal belt just north of Cape Ann we find very little difference in actual temperature between readings of 2.4° to 3.7° at the *Fish Hawk* stations (Nos. 20 to 28) for March 10, 1925, and Welsh's records of 3.8° to 3.9° on March 19, 1913; but with the surface about 1° warmer than the 30-meter level at all these *Fish Hawk* stations, but the whole column virtually uniform in temperature down to 120 meters in 1913, it is evident that the vernal warming of the surface commenced at least two weeks earlier there in 1925 than in 1913. The year 1920 was certainly colder at this general locality than either 1913 or 1925, because the surface had warmed only to 3.05° there by the 6th of April (station 20092).

The temperature of the upper 100 meters was 2° to 3° lower in the sink off the Isles of Shoals on March 5, 1920, than on that same date in 1921, and while the bottom readings for the two years differ by only about 0.1° in 175 meters, the bottom water was certainly slightly colder there in 1915 than in either 1920 or in 1921, a temperature of only 3.7° at 175 meters as late in the season as May 14 of that year contrasting with about 4° early in March of 1920 and 1921.

Essentially this same relationship between the early March temperatures for 1920 and for 1921 was recorded off Cape Elizabeth and off Seguin Island, 1920 being from 0.2° to 2.4° the colder year at all levels down to the bottom in 45 to 100 meters.

The temperatures of the western basin some 35 miles off Cape Ann for February 22 and March 24, 1920 (stations 20049 and 20087), and for March 5, 1921, did not differ by more than 1.2° at any level; in all cases the highest reading was at about 170 meters, with the upper 40 meters coldest, and 2.74° (on March 24, 1920) as the absolute minimum. On the whole, however, the readings for 1921 are slightly higher and the maximum for the month was recorded on that date (6.45° at 175 meters).

Thus 1920 may be described definitely as a cold winter in the coastal zone out to the 50-meter contour; 1921 and 1925 as warm ones. There was much less annual difference in temperature in the neighboring basin and almost none below the 200-meter level. A regional difference of this sort is just what might be expected if the winter chilling of the gulf is due chiefly to the severe climate of the neighboring land mass to the west (as there is every reason to believe it is), because the icy northwest winds, as they blow out over the adjacent sea, necessarily have most effect on the temperature of the water near the land.

VERNAL WARMING

After the middle or end of February the temperature of the western and northern parts of the gulf slowly rises as the heat given to the surface layers by the increasing strength of the sun is propagated downward by the vertical circulation of the water, but at different rates in different parts of the gulf, depending on the local activity of tidal stirring.

Were solar warming alone responsible for the warming of the gulf in spring, the change would, for the first month or two, be confined to the superficial stratum where this vertical mixing is most active, except where a deeper column is kept stirred by strong tides—the Bay of Fundy, for example, and parts of Georges Bank. Actually, however, the gulf also warms from below during the early spring as the slope water, comparatively high in temperature and which enters through the trough of the Eastern Channel (p. 526), is incorporated by mixture with the colder stratum above, any increase in the amount of this from season to season being betrayed by an increase in salinity as well as in temperature. During the first weeks of March the warming effected from below by this source raises the temperature of the deep waters of the inner part of the gulf as rapidly as solar heat warms the surface stratum.

It is interesting to trace the change that vernal warming effects in the level at which the gulf is coldest. Probably the inner parts are invariably coldest in the upper 40 meters by the end of winter, a state that persisted into the first week of

March in the years 1913 and 1921, as just noted (p. 524). In 1925, too, the superficial 10 meters of Massachusetts Bay did not become definitely and consistently warmer than the underlying water until the end of March (locally even later); and although the whole column had been warming slowly at all the stations there since the middle of February (p. 660), this change was at first so slow that the mean surface temperature of the southern side of the bay was only about 0.3° higher on March 10 (2° at stations 2, 10, 13a, 15, and 18a) than it had been on February 24 to 28, the mean bottom temperature for these same stations remaining virtually unchanged. This probably applies also to the whole area of Massachusetts Bay, for the surface had warmed by only about 0.56° just outside Gloucester Harbor, and not at all within the latter.

In Ipswich Bay, however, the surface had become definitely warmer than the underlying water by the first week of March, and this was the case over the gulf as a whole in 1920, as just described.

From early March onward the progressive warming from above lowers the coldest plane in the western side of the basin to a depth of about 100 meters by the middle or end of April. At the same time warming by slope water from below *raises* the coldest plane in the northeastern part of the basin (the latter itself now slightly warmer than in March) to within 15 to 20 meters of the surface. In the southeastern part of the basin, however, the temperature was lowest at the 100-meter level on April 17 (station 20112), instead of at 20 to 40 meters, as it had been on March 11 (station 20064). The minimum temperatures were recorded at about the same depth (20 to 40 meters) for the two months in the Northern Channel, the Eastern Channel, and on the southeastern continental slope of Georges Bank. On Browns Bank, however, where the upper 20 meters had been considerably coldest on March 13 (station 20072), the bottom (80 meters) was slightly coldest on April 16 (station 20106), and the whole column, top to bottom, had become nearly homogeneous in temperature during the interval.

Vernal warming, the normal event in boreal seas, is retarded—may even be reversed temporarily—in the eastern side of the Gulf of Maine when the intermittent Nova Scotian current floods past Cape Sable, as described in a later chapter (p. 832). The cold water from this source affects a greater displacement of the isotherms within the gulf and produces lower temperatures there in some springs than in others, depending on the volume and temperature of the flow past the cape, on the date at which this reaches its maximum, and on the duration of the period during which this Nova Scotian water enters the gulf in amount sufficient to appreciably affect the temperature of the latter.

In describing the spring cycle vernal warming must be carried along hand in hand with this chilling from the east. In 1913 the vernal warming of Massachusetts Bay and of the Isles of Shoals–Boon Island region to the north was at first most rapid on the bottom. Thus, the 82-meter temperature rose from 3.11° off Gloucester on February 13 (station 10053) to 3.61° on March 4 (station 10054), whereas the two surface readings were less than 0.1° apart (both 2.83° to 2.89°). Mr. Welsh found the surface still continuing fractionally colder (3.6°) than the deeper levels near Boon Island on the 29th of the month also, although, judging by the date, the superficial stratum almost certainly had experienced some increase in temperature by then.

It is probable that vernal warming followed a similar course, at first, in the coastal zone in 1921, with the indraft of warmer and salter water from offshore maintaining the winter status of cold surface stratum and warmer bottom water into the first week of March. In 1925, however (p. 1004), warming from above and from below raised the temperature of the whole column in Massachusetts Bay at a more nearly equal rate from the middle of February until late in March, whereas in Ipswich Bay the surface warmed the more rapidly from the beginning. In 1920, however, the surface was already fractionally warmer than the 20 to 40 meter stratum as early as March 4 (p. 524), and it may be that in any year when an extremely severe winter chills the upper 100 meters or so of the gulf to an abnormal degree the surface at once commences to warm after the grip of winter is released, whereas in more normal years the surface temperature may be expected to remain almost stationary for a brief period during late February and early March. In 1924, when a foot or so of snow fell on March 11 and 12, followed by several days of freezing weather, the surface had warmed to only 2.2° at a station 8 miles off Gloucester (*Halcyon* station 10652) by March 19, with about 1.8° at depths of 40 and 70 meters.

The progressive warming of Massachusetts Bay is illustrated for a warm April by the *Fish Hawk* stations for 1925, when the mean surface temperature rose from 2° on March 10 to about 4.6° on April 4 to 8. A definite regional differentiation also had developed, with the surface warmest (5° to 5.4°) in Cape Cod Bay, where it had been coldest during the preceding months. Thus, the relationship characteristic of winter (coldest next the land) was now definitely reversed, so to continue through the spring (fig. 22) and summer. At the 40-meter level, however, the bay still continued slightly warmer at its mouth (3.2° to 3.9°, *Fish Hawk* stations 30 to 33 and 34) than in Cape Cod Bay or near the Plymouth shore (2.9° and 2.6°, stations 6a and 10), evidence that the indraft of offshore water continued to exert more influence on the temperature of the deeper strata (up to the 7th or 8th of April in that year) than did solar warming from above. This was not the case in Ipswich Bay, however, where the 40-meter temperature was almost precisely the same on April 7 (2.4° to 2.8°) as it had been on March 10 (2.5° to 2.7°), though the surface had warmed from 3.35°–3.6° to 4.2°–4.9° during the interval.

By April 21 to 23 the mean temperature of the surface of Massachusetts Bay had risen to 5.2° (4° to 6.8° at the individual stations, fig. 22) and the 40-meter temperature to a mean value of about 3.8°, but virtually no change had yet taken place in the temperature of the bottom water at depths greater than 60 meters, a constancy illustrated by the following table. In 1920, also, the inner part of the bay was actually slightly colder at 40 meters on April 20 (1.58°) than it had been on April 6 to 9 (2.2°–2.4° at stations 20089 and 20090), evidence of some upwelling of the colder water from below.

Fish Hawk stations	Apr. 7 and 8, 1925		Apr. 21 to 23, 1925	
	Meters	*Degrees*	*Meters*	*Degrees*
No. 33	80	2.91	60	3.06
No. 30	84	3.11	80	2.92
No. 31	112	2.9	84	2.7

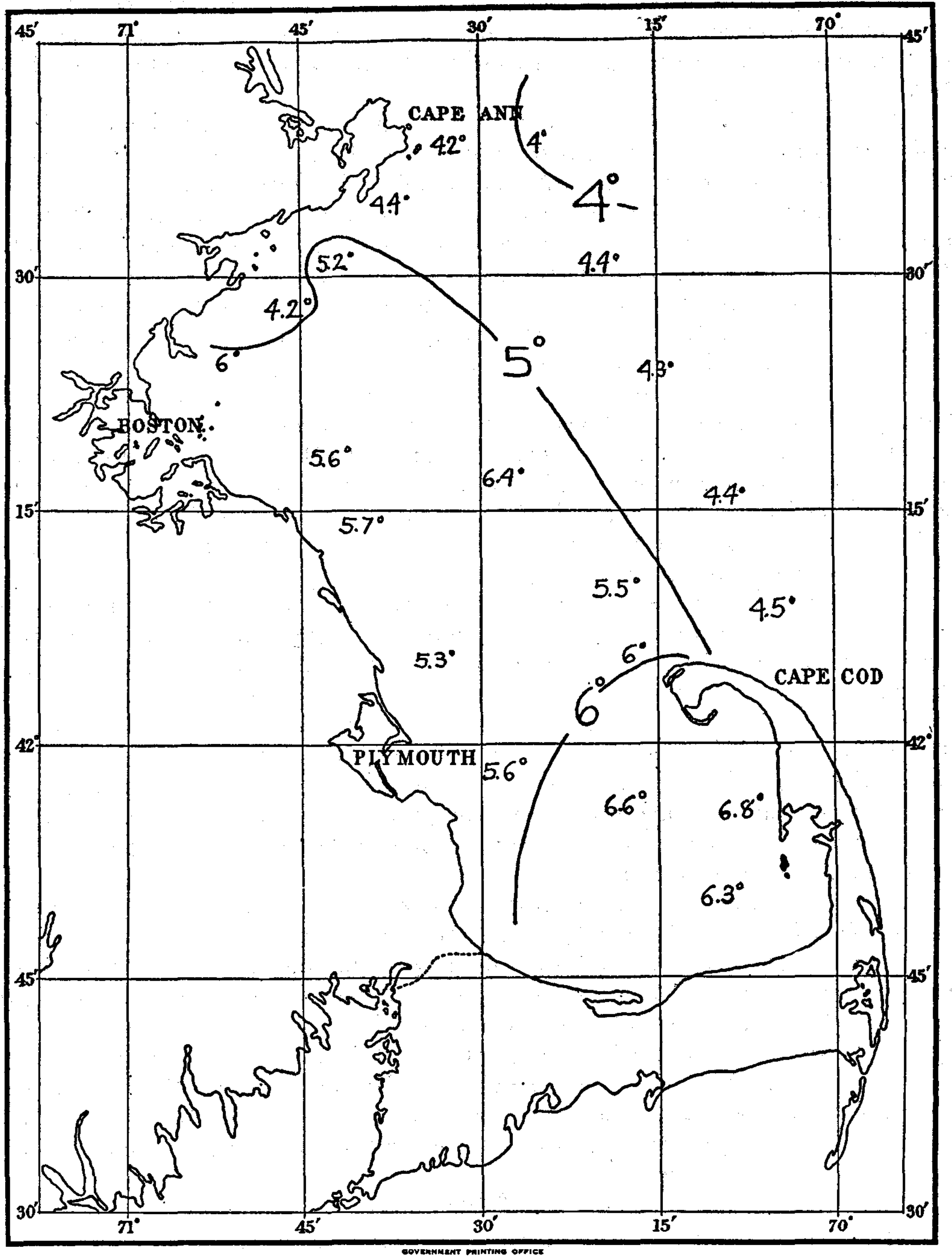

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FIG. 22.—Surface temperature of Massachusetts Bay, April 21 to 23, 1925

The temperature followed a similar cycle in 1913, when the surface warmed to 5.56° near Gloucester by April 14, though no appreciable change had taken place at 25 meters during the preceding two weeks (about 4° to 4.1°; stations 10055 and 10056).

In 1923, following a very severe winter, the surface of the central part of the bay had warmed to only 2.8° by April 18, with 1.6° at 40 meters and 0.4° at the bottom in 80 meters. The bay continued nearly as cold as this until the end of April in 1920 (also following a cold winter) with readings of 3.6° at the surface, 2.87° at 20 meters, 1.58° at 40 meters, and 1.78° at 90 meters in its central part on the 20th (station 20119), but with the regional distribution (warmest, 4.4° in Cape Cod Bay, station 20118) essentially the same as in 1925. Probably the records for 1925, on the one hand, and 1920 and 1923, on the other, cover the extremes to be expected in the bay in April, except in very exceptional years.

Seasonal progression in the coastwise belt north of Cape Ann is illustrated for a warm year by serial observations taken by W. W. Welsh near the Isles of shoals and near Boon Island at intervals during the spring of 1913 (p. 980). Here the winter state prevailed until the end of March (fig. 23). On April 5 the temperature was equalized, surface to bottom, and after the middle of the month the surface was warmer than the underlying layers, warming progressively thereafter as illustrated by the graph (see also Bigelow, 1914a, p. 394).

The rate at which the surface warms along this part of the shore during April is irregular, often interrupted or even temporarily reversed by climatic conditions. During the winter, when the column of water is of nearly uniform temperature from the surface downward, the upwellings that follow offshore winds have little effect on the surface temperature; but as soon as the surface becomes appreciably warmer than the underlying water, any upwelling of the latter, or vertical mixing, is at once made evident by a decided, if temporary, chilling of the surface. Northwest winds are a frequent cause of such upwellings along the western shores of the gulf in early spring, and a blow from any quarter causes a more or less active stirring of the uppermost stratum by wave action.

During the spring of 1913 a northwesterly gale cooled the surface from 5° near the Isles of Shoals on April 13 to 4.6° on the 14th and 15th. The water then warmed to 7.9° by April 26, under the influence of unseasonably warm weather, when a northeasterly gale, with rain, followed by high northwest winds, once more chilled the surface to 6.7°. This was followed by another rise in surface temperature to 9.78° by May 6, when a third northwest gale, of several days duration, once more reduced it to about 7.2°. The wind then changed to the south, and by the 14th of May, when the latest observation was made, the surface temperature had risen to 8.11°.[10] Temporary upwellings of this sort are as clearly evidenced by a rise in salinity (p. 729) as by a fall in temperature.

APRIL

It is necessary to turn to the station data for 1920, combined with odd records for 1913 (p. 980) and 1925 (p. 1012), for a general picture of the temperature of the offshore waters of the gulf in April, remembering that after a mild winter readings 1° to 2° higher than those pictured (fig. 24) are to be expected in the coastal belt.

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[10] For further details see Bigelow, 1914a, p. 395, fig. 7.

In 1920 the entire surface of the open gulf ranged between 3° and 4° by April 9 to 20, including the eastern part of Georges Bank, the Eastern Channel, and Browns Bank; except for one station on Platts Bank (20094), where active vertical circulation caused a fractionally lower surface reading (2.78°), and off the Kennebec River (station 20096, 2.78°), where a very low surface salinity (29.94 per mille, p. 1001) was unmistakable evidence of freshet water. In 1925 the surface of the coastal belt (Cape Ann to Mount Desert) was about 1 degree warmer at this season (*Halcyon* records, p. 1012), grading (south to north) from 5.5° to 2.5°–3.8°, though with the water to the eastward of Cape Elizabeth still continuing coldest next the land.[11]

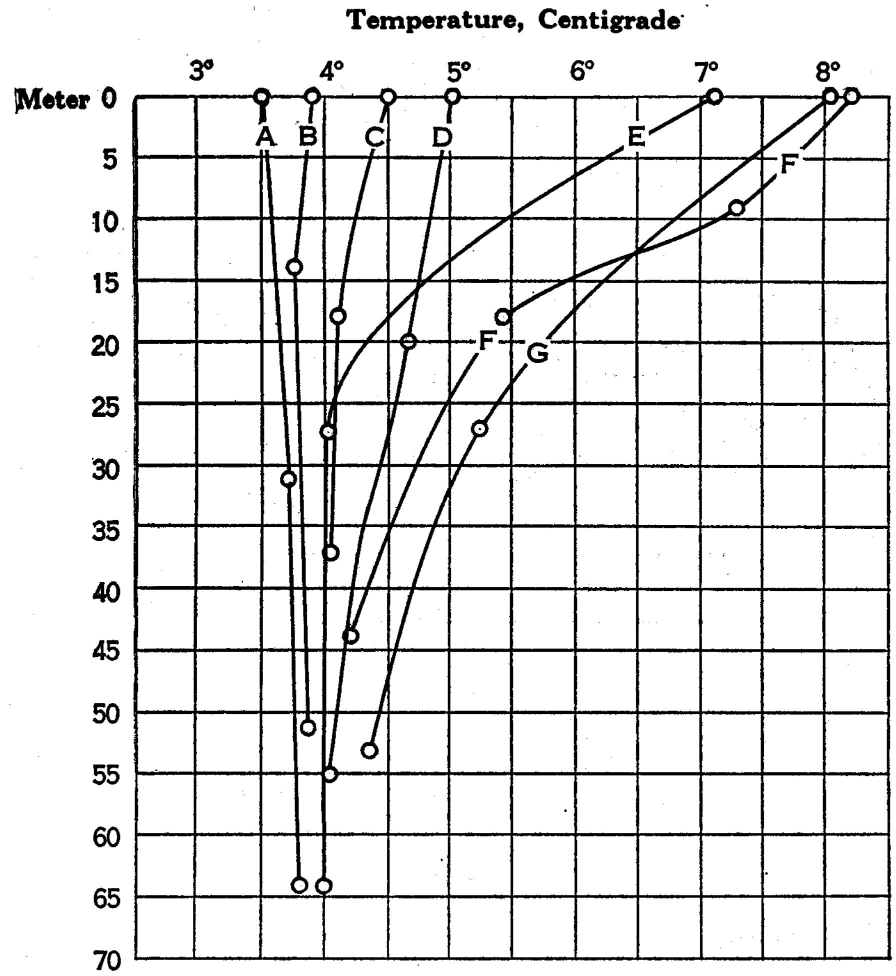

FIG. 23.—Vertical distribution of temperature near the Isles of Shoals and Boone Island at successive dates of the year 1913, to show the progress of vernal warming. A, March 29, 1913; B, April 5 (both near Boone Island); C, April 13; D, April 16; E, April 29; F, May 8; G, May 14 (C and F are near the Isles of Shoals)

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[11] Close in to Boothbay 3.3°, but 4.4° near Seguin Island; 1.9° in Southwest Harbor, but 3 to 3.8° near Duck Island, off Mount Desert Island.

No temperatures were taken on the western part of Georges Bank or on Nantucket Shoals during April, 1920. In 1913 Mr. Douthart had surface readings of 6.6° on the northern part of Georges Bank on April 11 and 15, with 7.7° on its western side

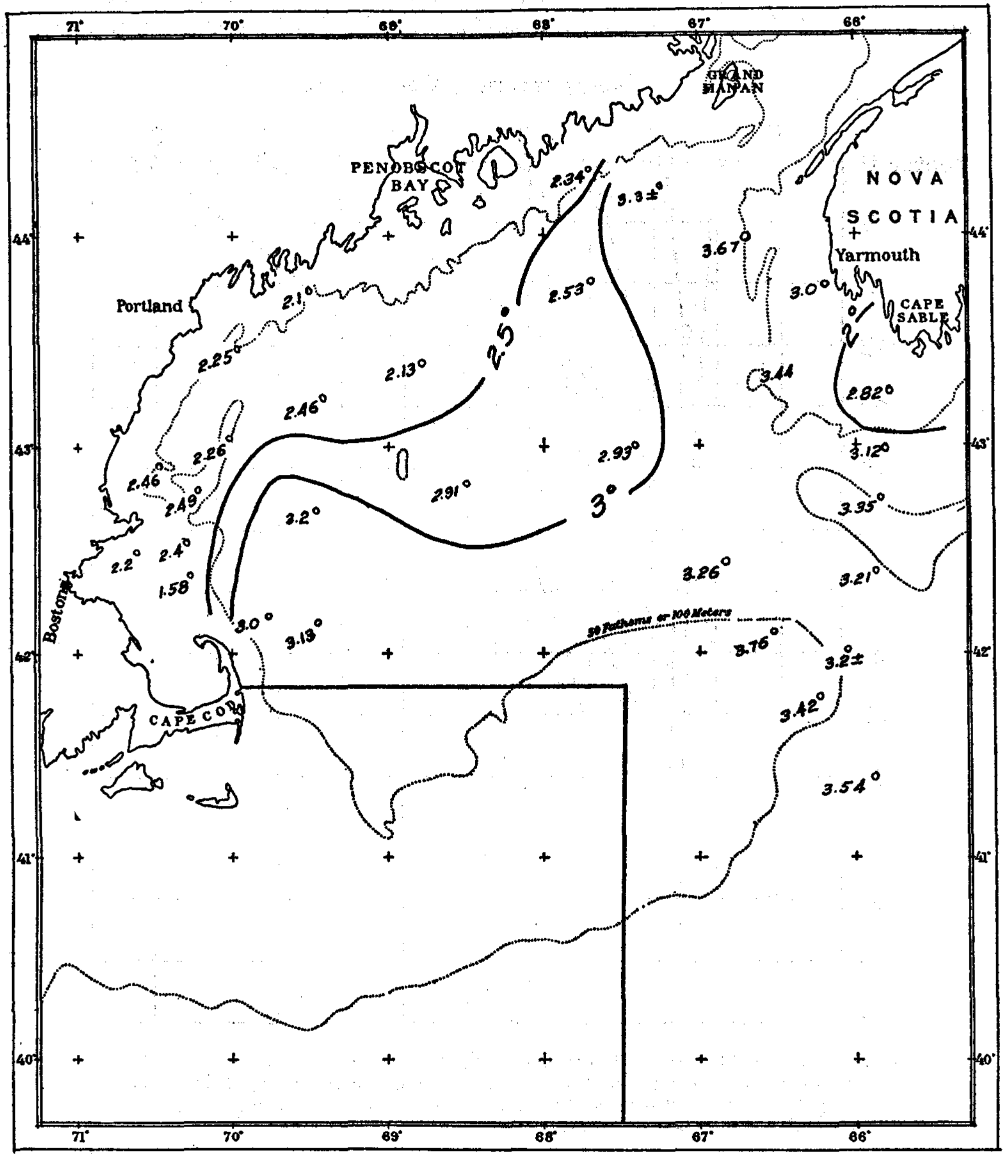

FIG. 24.—Temperature at a depth of 40 meters, April 6 to 20, 1920

on the 27th (p. 980). Taking into account the annual differences between early and tardy springs, temperatures about 2° lower might have been expected at these stations and dates in 1920. A surface reading of 3.3° on Rose and Crown Shoal near Nantucket Island on April 27, 1923 (p. 996) suggests that the surface has about the same temperature over Nantucket Shoals as that of the western and southwestern parts of the gulf generally at this season.

In 1920 the surface warmed by about 2° all along the belt from Massachusetts Bay to the Bay of Fundy from mid-March to mid-April; by less than 2° over the basin generally and along western Nova Scotia; by less than 1° on the eastern part of Georges Bank; and there had been no measurable change in surface temperature in the Eastern Channel (stations 20071 and 20107, 3.33°). In other words, where the surface is most chilled in winter it warms most rapidly in early spring.

The fact that the surface temperature increased over the German Bank–Cape Sable area and out across Browns Bank from March to April, 1920, is proof that the westward flow of Nova Scotian water, chilled by ice melting far to the eastward (p. 832), did not impress the temperatures of the gulf until still later in that spring, marking 1920 as a "tardy" year in this respect as in others. The opposite extreme is illustrated by a surface reading of 0° in the eastern side of the basin (the lowest yet recorded for the open gulf)[12] on March 28, 1919,[13] explicable only by some movement of cold water from the east, though as so thin a surface layer that neither the temperature nor the salinity were appreciably affected by it more than 20 to 30 meters downward.

In 1920 the mean temperature of the 40-meter level proved about 0.8° warmer in mid-April (fig. 24) than in mid-March, with this change greatest (1° to 1.67°) in the eastern side of the basin and off western Nova Scotia, resulting in a general equalization at 2.2° to 3° for the whole western and northwestern parts of the gulf, with 3° to 3.7° over the southern and eastern parts. In the warmer spring of 1925 the *Halcyon* found the 40-meter level about half a degree warmer—namely, about 3.2°—four miles off Cape Ann whistle buoy on April 17; 2.8° close to little Duck Island (off Mount Desert) on the 19th; and 2.9° eight miles out from Duck Island on that same day.

The progressive change in temperature was not so regular from March to April at depths greater than 40 to 50 meters in 1920, and wherever warming took place in the deep strata during the interval, it was accompanied by a corresponding rise in salinity, proving the source of heat to be warmer bottom water, solar warming not having penetrated more than a few meters downward as yet.

Thus the inner parts of the gulf north of the Cape Cod–Cape Sable line warmed by about as much (about 1.7°) from mid-March to mid-April at 100 meters (fig. 25) as at the surface. Virtually no change took place meantime in the 100-meter readings in the southern part of the basin, while the 100-meter level had cooled by nearly 1° in the southeastern part of the area, a change accompanied by a corresponding decrease in salinity (p. 735). Thus, it seems that the middle of April is the coldest season of the year in this region at this depth. This regional difference in the rate and order of the seasonal change of temperature tended to equalize the mid-stratum over the gulf as a whole, so instead of the regional range of nearly 5° obtaining at 100 meters in March (fig. 13), the highest and lowest readings at this depth were only 3.56° apart in April (fig. 25). While the general distribution of temperature remained the same—lowest (3° to 3.5°) along

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[12] This reading is corroborated by a correspondingly low salinity (p. 727).

[13] Ice patrol stations 1 to 3, p. 997.

the western slope of the basin and in the sink off Cape Ann, highest (4° to 6°) in the eastern side and in the Eastern Channel—the isotherms for April (fig. 25) do not outline the warm indraft into the eastern side as clearly as do those for March (fig. 13).

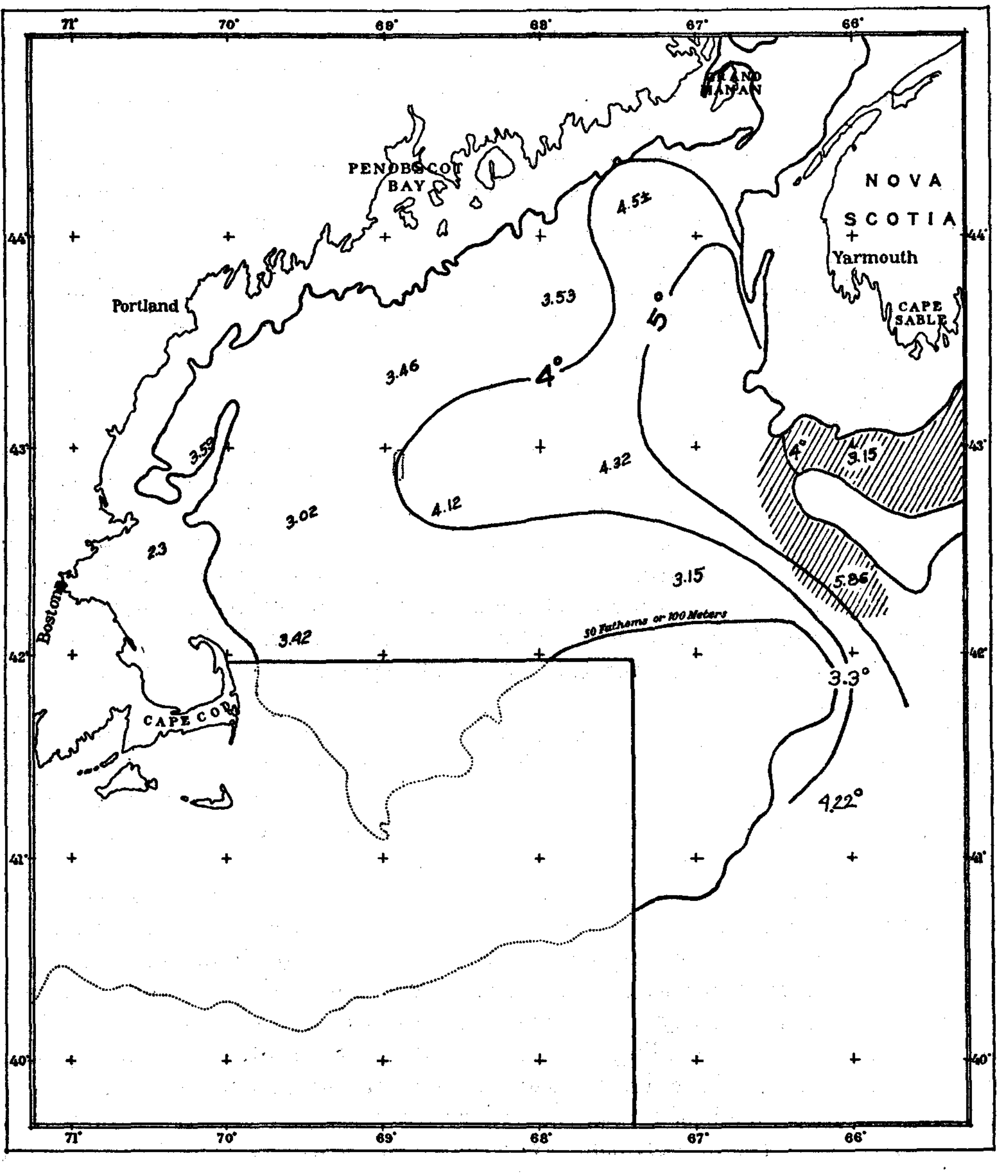

FIG. 25.—Temperature at a depth of 100 meters, April 6 to 20, 1920. The shaded area was colder in April than in March

Unfortunately the data do not afford an annual comparison for depths as great as this, no readings having been taken so deep in April, 1925; but temperatures of 2.7° to 2.9° at 80 to 84 meters in Massachusetts Bay on April 21 to 23 of that year, and of 2.9° at 91 meters at a station 8 miles off Little Duck Island (off Mount

Desert) on the 19th, are interesting as evidence that this general stratum was apparently no warmer in that spring than in the corresponding month of 1920, although the upper 40 meters of water was considerably so. Thus, as the depth increases, annual variations, like seasonal and regional variations, tend to diminish until a level is reached below which the temperature is governed chiefly by pulses in the bottom drift flowing in from the edge of the continent.

The bottom water at and below 200 meters was fractionally cooler in the eastern arm of the basin in April, 1920, than it had been in March, and fractionally warmer off the northern slope of Georges Bank and off Cape Ann (station 20115, 6.36° at 200 meters), with the deepest readings ranging only from 4.73° to 5.28° at 200 to 290 meters in the basin, rising to 6.07° in the Eastern Channel (station 20107). No observations were taken as deep as this on the continental slope in April, but a reading of 6.47° at 150 meters off the southeast face of Georges Bank on the 16th (station 20109) shows a rise of about 1.6° since March 12 (station 20068).

In March, 1920, it will be recalled (p. 541), the trough of the Eastern Channel below 100 meters was filled with water warmer than 6°, though no temperatures as high as this were encountered anywhere within the gulf. By mid-April, however, still warmer water (7.45° at 170 meters, fig. 26) had penetrated the channel, its effect (6 to 6.39°) spreading inward to the western side of the basin off Cape Ann (station 20115) as a thin stratum at 180 to 260 meters, but with slightly cooler (4.92°) water below it.[14]

Again, on March 5, 1921, there was a thin, warm stratum (6° to 6.4°) at 160 to 210 meters off Cape Ann. Evidently, therefore, temperatures as high as 6° may be expected below about 175 to 200 meters in the western arm of the basin of the gulf at any time from March to April (in summer, also), though not invariably. This warm stratum, when it occurs, may either be sandwiched in between lower temperatures in the bottom of the trough below, as well as above, or may extend right down to the bottom, with the vertical distribution of temperature following the curves shown in the accompanying graphs (figs. 3 and 5).

Temperature and salinity combined establish the Eastern Channel as the source of this indraft into the bottom of the gulf. Its course across the latter (unfortunately not chartable in detail from the data yet on hand) is discussed in a later chapter (p. 921). There is strong evidence that it takes the form of intermittent pulses, the 6°-water encountered off Cape Ann in April, 1920 (station 20115), being the result of such a pulse; for it seems to have been entirely cut off from the still warmer source in the Eastern Channel at the time by fractionally lower temperatures in the southeastern bowl of the gulf (stations 20112 and 20113).

These pulses are so important in the general circulatory system of the Gulf of Maine that an April profile along the arc of the banks (fig. 26) is introduced here for comparison with that of the preceding month (fig. 19). The most important seasonal alteration is the rise in temperature at 150 to 200 meters in the channel just mentioned, which could only result from the actual introduction of water of still higher temperature from offshore. On the other hand, vernal warming from above and a delay in the westward flood of Nova Scotian water until later in the

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[14] No readings so high were obtained anywhere in the southern or eastern parts of the basin that April, the maxima being respectively, 5.28°, 5.14°, 5.28°, and 5.16° in depths of 210, 225, 175, and 165 to 230 meters at stations 20098, 20100, 20107, 20112, and 20113

spring than this event is usually to be expected allowed a decided warming of the upper stratum to 2.8° to 3.5° from the Cape Sable slope out to Browns Bank, though with very little change from March to April on the Georges Bank side.

MAY

SURFACE

From late April, on, the temperature of the western side of the gulf constantly rises, most rapidly at the surface, progressively slower with increasing depth. Near Cape Sable, in the eastern side, however, the vernal cycle is dependent on the volume, temperature, and seasonal "time table" of the Nova Scotia current. Where this debouches into the gulf the surface stratum is at its coldest some time in April or even as early as the last of March in "early" years (1919, for instance), but not until May in "late" years, as probably happened in 1920. Unfortunately, neither of our May cruises (1915, 1920, or 1925), nor the ice patrols stations for 1919, has covered the gulf as a whole; hence I can offer only a composite picture for the month, based on years that certainly differed considerably in the rate of vernal warming and in the date at which the chilling effect of the Nova Scotian current reached its maximum.

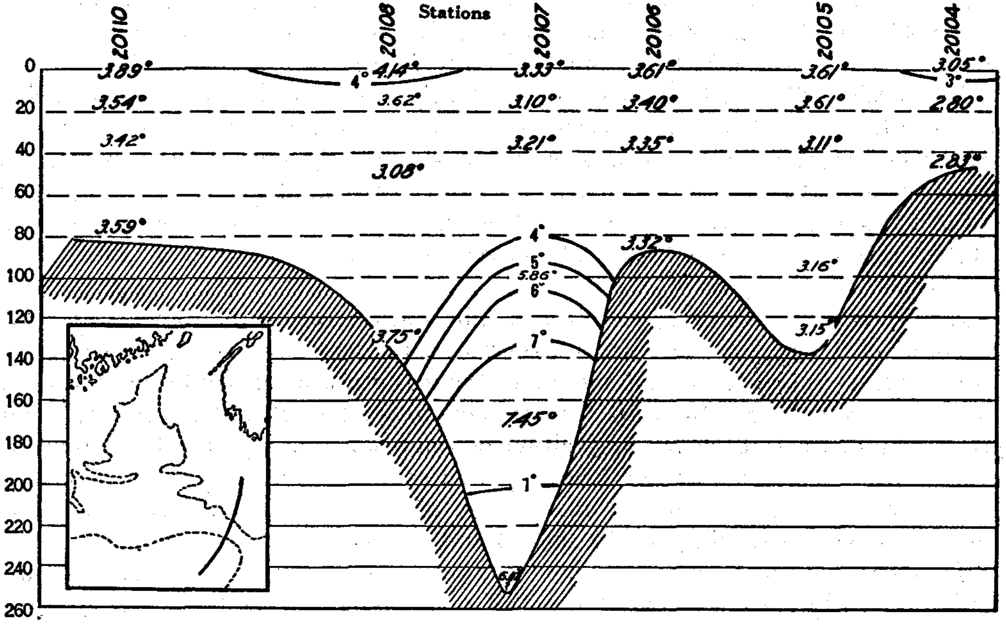

FIG. 26.—Temperature profile running from the eastern part of Georges Bank, across the Eastern Channel, Brown's Bank, and the Northern Channel, for April 15 and 16, 1920

On this basis the highest surface temperatures of early May (fig. 27) are to be expected in Massachusetts Bay, the lowest in the Cape Sable-German Bank region, with the whole area west of the longitude of Penobscot Bay warmer than 6° by the 10th, if not earlier, contrasted with surface readings of about 3° or lower off western Nova Scotia.[15]

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[15] Three degrees on German Bank, May 9, 1915 (station 10271); 2.7° there on Apr. 28, 1919 (ice patrol station No. 22)

In 1915 a west-east gradation in surface temperature was recorded along the coast of Maine from May 10 to 14, from 7.8° near the Isles of Shoals and off Casco Bay to 5° off Penobscot Bay and 4.2° to 4.8° near Mount Desert Island. No doubt the precise readings vary with the state of the weather, however, as well as with the date and exact locality and from year to year. I must also caution the reader that at this season the surface temperature is changing so rapidly in the western side of the gulf that a difference of a few days, one way or another, will make a considerable difference in the readings obtained; less so in the eastern side.

Although the precise surface temperatures at any given date vary from one May to the next, depending largely on the forwardness of the season on the land, probably the comparative rates of vernal warming do not vary widely from year to year in different parts of the gulf.

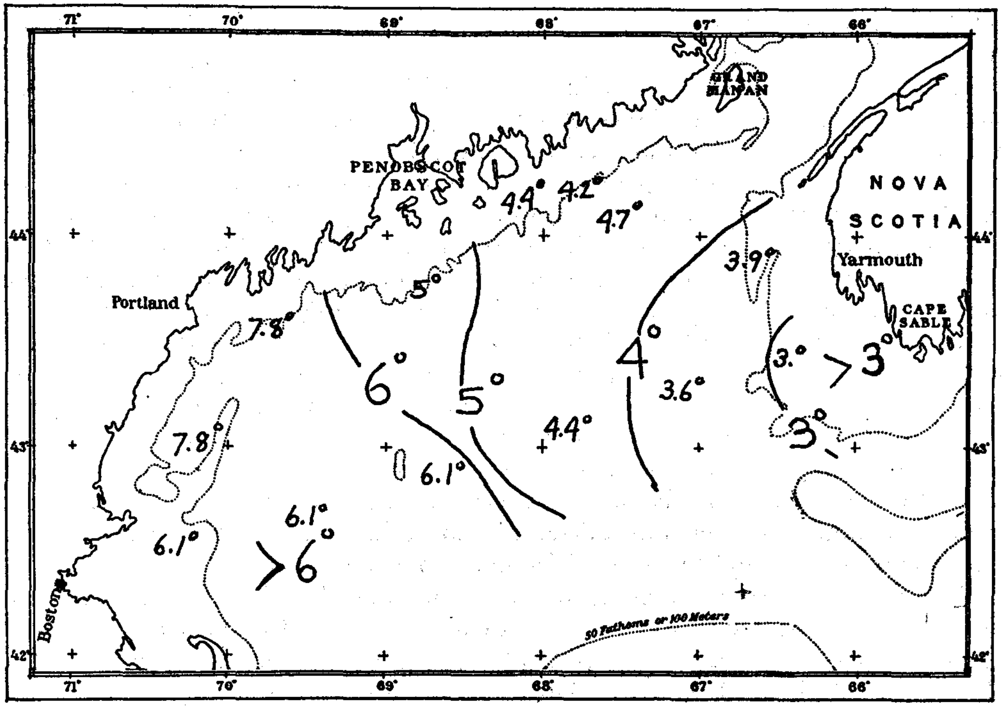

FIG. 27.—Surface temperature, first half of May, 1915

It appears from combining the records for the three years 1913, 1915, and 1920, that this change is most rapid in the inner part of Massachusetts Bay, where the surface warmed from 3.05° on April 6 (station 20089) to 8.89° on May 16 (station 20123) in 1920. Similarly, temperatures taken by the *Fish Hawk* in 1925 show the surface of the southern side of the bay, generally, warming from 5.3° to 6.8° on April 21 to 23, to 7° to 11° on May 20 to 22.

At the mouth of the bay, where the surface does not chill to so low a figure at the end of the winter, a less rapid rate of vernal warming causes about the same

May temperatures. In 1925, for instance, the surface temperature at a line of stations from Cape Ann to Cape Cod rose from 4.3° to 4.4° on April 21 to 23 to 8.3° to 9.4° on May 20 to 22 (*Fish Hawk* cruise 13); and vernal warming proceeded at about this same rate there in 1920, when the surface reading rose from 2.5° off Gloucester on March 1 (station 20050) and 3.3° on April 9 (station 20090) to 6.39° on May 4 (station 20120) and 9.72° on May 16 (station 20124).

This thermal change is accompanied by an alteration in the regional distribution of surface temperature over the bay. Cape Cod Bay continues to be its warmest center, the immediate vicinity of its northern coast line its coldest, reflecting local stirring by the tide or some upwelling, as is the case in April (fig. 22). In 1925, however, the summer state was foreshadowed, as early as the last week in May, by slightly higher surface readings (9°) at the outer stations than between Stellwagen Bank and the shore (fig. 28).

The surface of Ipswich Bay, just north of Cape Ann, warms as rapidly from April through May as does Massachusetts Bay, judging from readings of 3.05° on April 9, 1920 (station 20092) and 7.22° on May 7 and 8 (station 20122).

Similarly, the surface temperature of the basin abreast of northern Cape Cod rose from 3.61° on April 19 (station 20116) to 9.17° on May 16 (station 20125); the surface of Gloucester and Boothbay Harbors rose from about 4° to about 9° between April 15 and May 15, and Lubec Channel from about 2° to about 5° during this same interval (figs. 29 to 31). As Doctor McMurrich[16] records a rise from about −1.67° at St. Andrews, on March 3, to about 5° to 6° in mid-May after the very cold and snowy winter of 1916, when the water was about 1° colder there than it was in 1917 (Willey, 1921) or than it is likely to be again for some years to come, the surface may be expected to warm by about 5° to 6° between the middle of April and the middle of May all along the western and northern shores of the gulf and out over the southwestern part of the basin generally. This warming, however, is made irregular, no doubt, or even intermittent, by local fluctuations in the weather (e. g., belated snowstorms) and by the cold freshets from the rivers.

The rise in surface temperature proceeds somewhat less rapidly out across Georges Bank, on the southwestern side of which we found the surface only about 3° warmer on May 17, 1920 (stations 20128 and 20129), than it had been there on February 22 (stations 20045 and 20046). Vernal warming is also less and less rapid from west to east across the gulf (fig. 32), with readings only fractionally higher along the coast of Maine east of Mount Desert Island on May 10 and 11, 1915, than on April 12, 1920, or between Grand Manan and Nova Scotia in 1917.[17]

Whether the surface stratum is warmer or colder in May than in April, from southern Nova Scotia out across German Bank (where the Nova Scotian current from the eastward exerts its chief effect), depends on the date when this current reaches its maximum and slackens again, events that certainly fall several weeks earlier in some years than in others. In 1919, as noted above (p. 553), icy water from this source was pouring into the gulf as early as the last week of March in volume sufficient to chill the surface to 0° as far west as the eastern side of the basin; but

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[16] Plankton lists (p. 513).

[17] Mavor (1923, p. 375) records the surface at *Prince* station 3 as 2.27° on Apr. 9, 1917, and 2.96° on May 4.

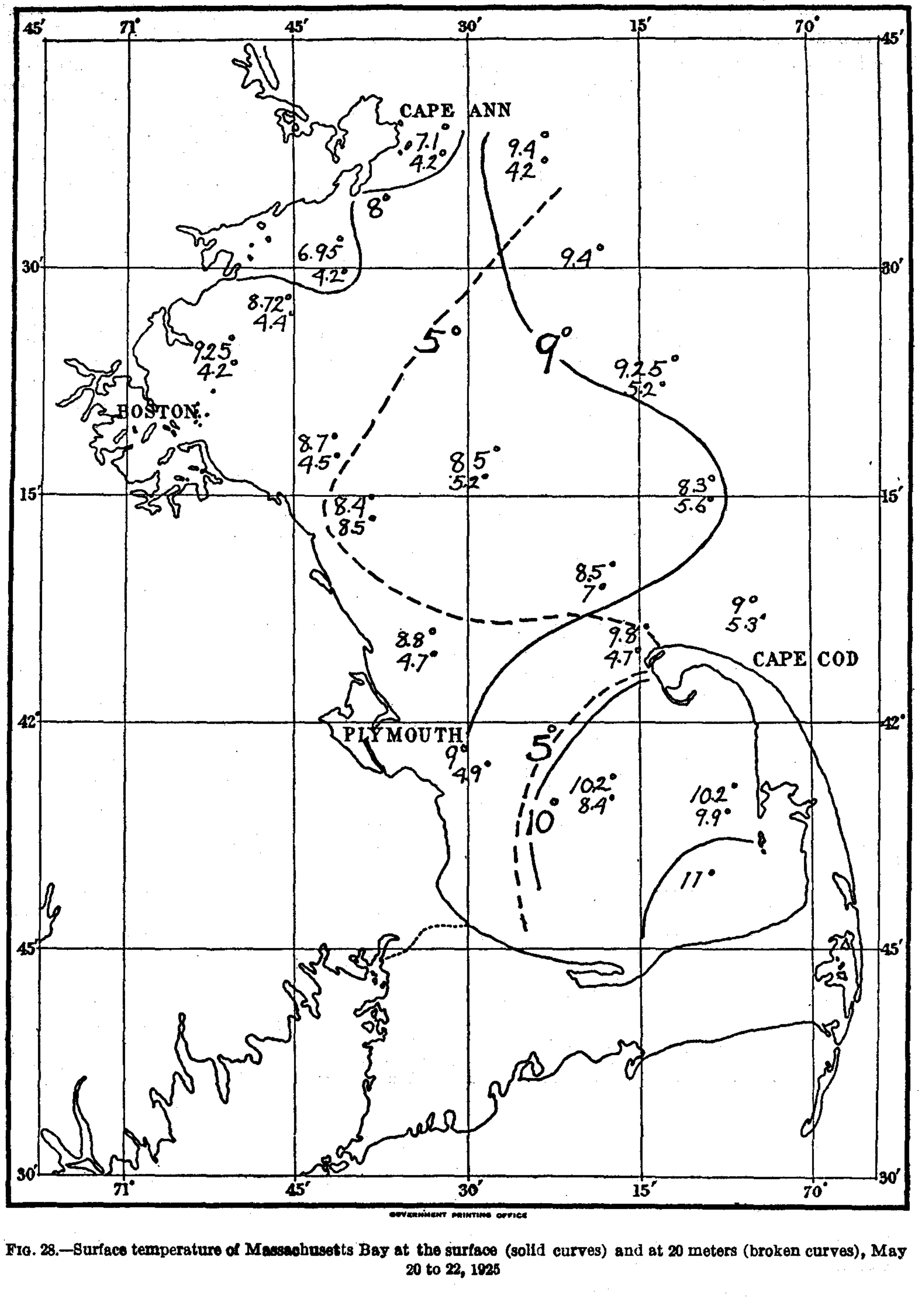

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FIG. 28.—Surface temperature of Massachusetts Bay at the surface (solid curves) and at 20 meters (broken curves), May 20 to 22, 1925

its flow must then have slackened (or its temperature have risen), because the surface temperature of the critical locality rose to 4.6° by April 28 and to 7.8° on May 29, though the whole column of water on German Bank was still only 2.7° and 4.2°, respectively, on these dates (ice patrol stations 3, 21, 22, 37, and 38, p. 997). The seasonal time-table seems to have been about the same in 1915, when the cold Nova Scotian water was responsible for a temperature of about 3° from German Bank out across the eastern side of the basin on May 6 to 7 (fig. 27), suggesting that the inrush into the gulf had reached its head some time in late March or April of that year. In 1920, however, it is certain that the cold current did not begin to flood past Cape Sable into the gulf in any considerable volume until after the middle of April.

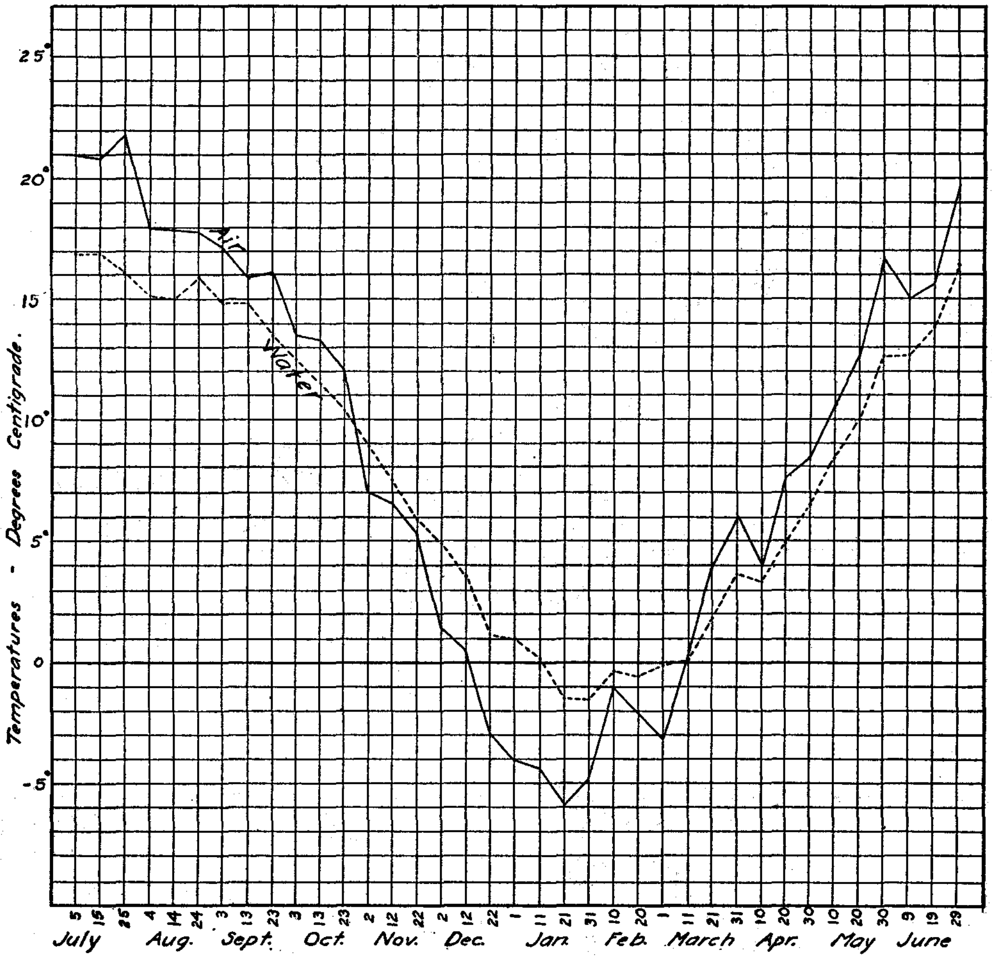

FIG. 29.—Mean air temperature (solid curve) and water temperature (broken curve) for 10-day intervals at Ten Pound Island, Gloucester Harbor, Mass., from July 1, 1919, to June 30, 1920

Water as cold as 0.27° to 0.56° had, it is true, spread westward past La Have Bank to within a few miles of the longitude of Cape Sable as early as the 19th of March, 1920 (station 20075); but this seems to have constituted its western boundary during the next four weeks, because the whole column warmed by about 1° on German Bank and near the Cape between March 23 and April 15 (stations 20085 and 20103, 20084 and 20104), instead of chilling, or at least remaining stationary in temperature, as would have happened with any considerable flow of 0° to 1° water from the east. Nor did any extension of icy water develop to the southwestward along the offshore banks or continental slope during the interval.

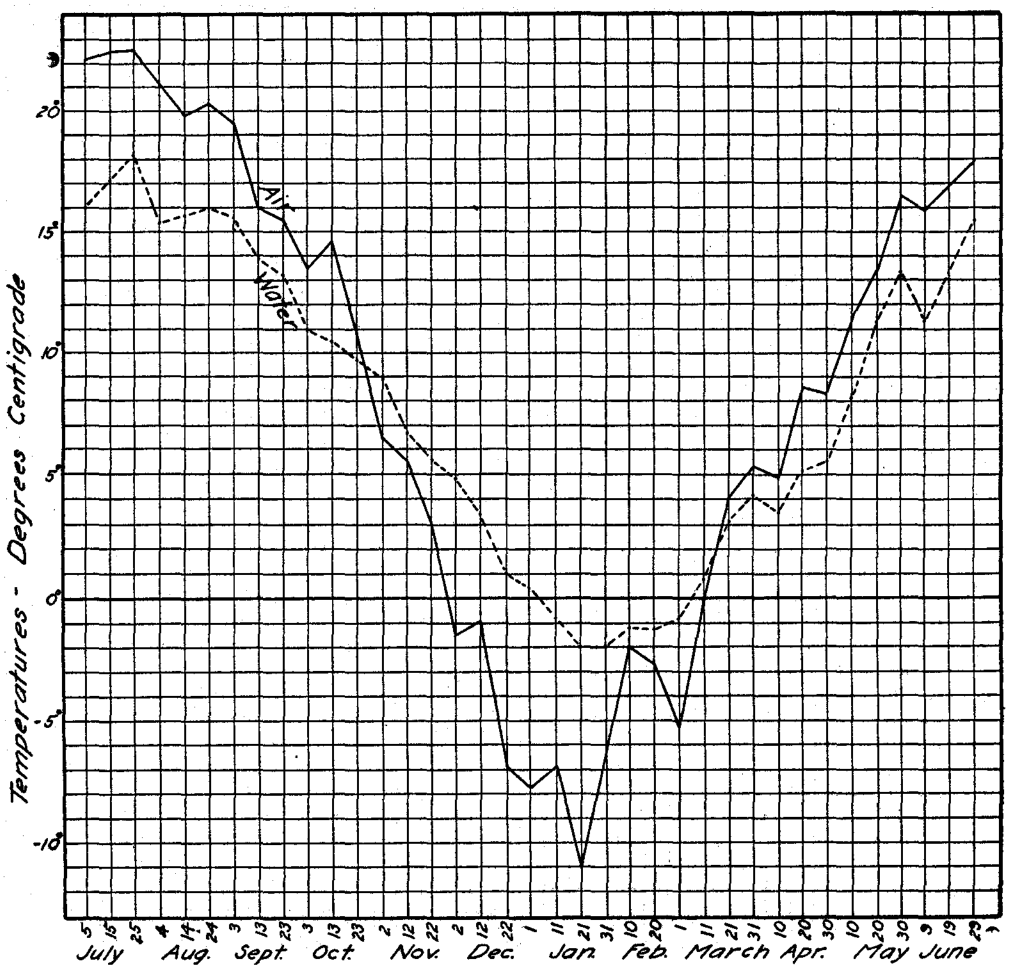

FIG. 30.—Mean air temperature (solid curve) and water temperature (broken curve) in Boothbay Harbor, Me., for 10-day intervals from July 1, 1919, to June 30, 1920

The greatest inflow of this cold water into the gulf may therefore be expected between the last week of March and the middle of April in "early" years, but not until the last of April or first part of May in "late" years. In spite of this annual variation in date, the close agreement between the late April–early May temperatures of 1915 and 1919 in the region most affected by it, and the uniformity in temperature in the eastern side of the gulf summer after summer, enlarged on below

(p. 626), suggests that it is not only a regular annual event but that the inflow from this source is comparatively uniform, both in volume and in temperature, from year to year. Its chilling effect on the surface temperature certainly extends northward along the Nova Scotian slope of the gulf as far as the neighborhood of Lurcher Shoal, where the whole column of water in 90 to 140 meters was about 0.4° colder on May 10, 1915 (station 10272), than on April 12, 1920 (station 20101)—just the reverse of the seasonal change to be expected.

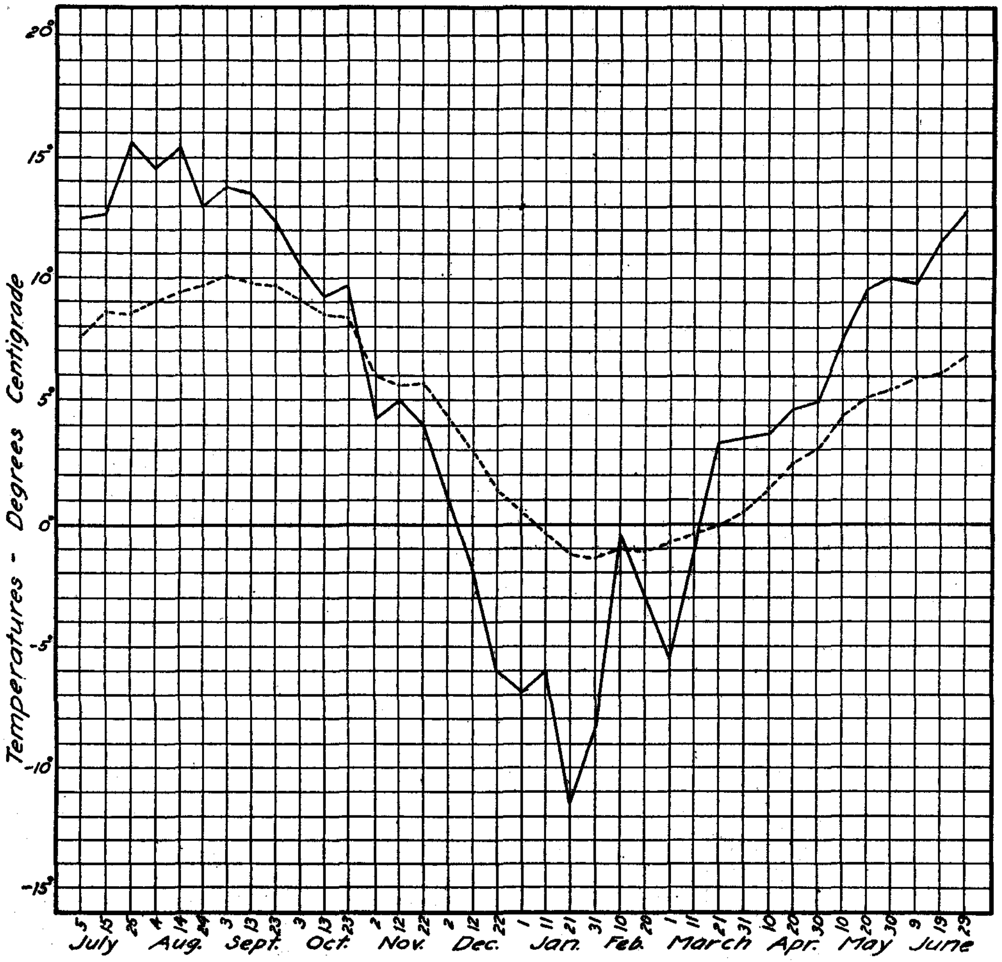

FIG. 31.—Mean air temperature (solid curve) and water temperature (broken curve) in Lubec Narrows, for 10-day intervals from July 1, 1919, to June 30, 1920.

It is much to be regretted that no data are available for May for the region from Cape Sable out across Browns Bank, the Eastern Channel, or the eastern end of Georges Bank. Lacking such, I can not outline the effect of the Nova Scotian current in this direction. Probably, however, icy water from this eastern source overflows Browns Bank at some time during April or May, perhaps the eastern end of

Georges Bank, also; and the presence of a band of water cooler than its immediate surroundings along the outer side of the latter bank and off Marthas Vineyard in summer (p. 608) suggests its influence.

It is still an open question how far westward into the gulf the vernal warming of the surface is retarded by this same agency. Even without its chilling effect, the surface probably would not warm as rapidly in the eastern side of the gulf as in the western, because the heat received there from the sun is more rapidly dispersed downward by more active vertical tidal stirring. Consequently, a slight west–east differential in surface temperatures, late in spring or early in summer, does not necessarily imply cold water from the eastward as its cause unless it reflects a corresponding difference in the mean temperature of the upper 40 to 60 meters.

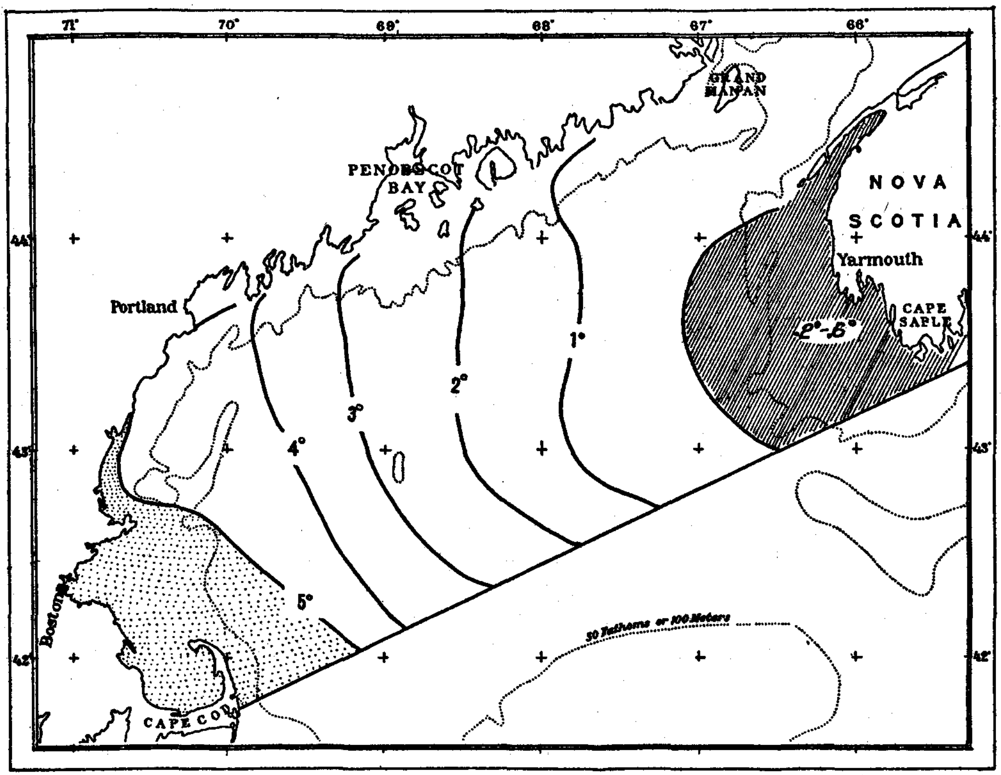

FIG. 32.—Normal rise in surface temperature from mid-April to mid-May. The hatched area experiences cooling

Up to the present time we have found no positive thermal evidence of the Nova Scotian water beyond the eastern arm of the basin (the situation of ice patrol station No. 3, p. 997); and the temperature (salinity, too) of the gulf is so uniform from summer to summer that vernal chilling from this source is not to be expected farther west than this, unless an exceptional spring may see a much greater inflow of cold water from the east than usual past Cape Sable.

BELOW THE SURFACE

In the northern and western parts of the Gulf of Maine, to which the chilling effect of the cold Nova Scotian water does not reach and which are only indirectly affected by the shoreward and seaward oscillations of the warm oceanic water outside the edge of the continent, the superficial stratum, down to say 20 meters, is sensibly warmer by mid-May than in April. The surface, also, warms so much faster than the water only a few meters down that a temperature gradient of several degrees develops over all this part of the gulf by the end of May as the first step in the transformation from the homogeneous state that characterizes the upper 100 meters at the end of the winter (p. 523) to the very steep gradient of summer (p. 596).

Thus, the mean temperature of the 20-meter level of Massachusetts Bay was only about 1° higher on May 20 to 22, 1925 (about 5.5°), than it had been on April 21 to 23, the difference between this depth and the surface having now increased to about 3° to 5°, except around the shores of Cape Cod Bay, where tidal stirring was active enough to maintain a more homogeneous state (*Fish Hawk* cruise 13, stations 6 and 7). Local differences of this sort, in the rate at which heat is transferred downward into the bay during the spring, were responsible for a regional variation of about 6° (from 4° to 9.9°) in the temperature of its 20-meter level at this date, and for a regional distribution (warmest in Cape Cod Bay) paralleling the surface (fig. 28); but evidently they had not yet been effective much deeper than 20 meters, because the temperature of the bay still continued virtually uniform from station to station at the 40-meter level and at nearly the same values (3.3° to 3.8°) as it had a month earlier.

While the deepest water of the bay (at 70 to 80 meters level) had warmed by about 0.2° meantime, the source of heat in this case was probably the bottom water offshore. Similarly, the 40 to 60 meter level of the bay warmed by only 0.6° in 1920 between April 9 (station 20090, 2.3°) and May 16 (station 20124, 2.9°); the bottom water in 100 to 120 meters by only about 0.4° (from 2.3° to 2.7°), although the surface temperature rose by about 6.4° meantime. In short, seasonal warming is negligible at depths greater than 25 to 30 meters until after the third week of May in the Massachusetts Bay region.

This statement applies equally to Ipswich Bay north of Cape Ann, where the 20-meter level warmed from 1.94° to 4.18° between April 9 and May 7 to 8, 1920, and the 40-meter level only from 2.45° to about 3.1° (stations 20092 and 20122), with no appreciable change at depths greater than 60 meters, so that the vertical range of temperature between the surface and 40 meters increased from only about 1° to nearly 5° during the 4 weeks' interval (fig. 33).

In the basin off the northern part of Cape Cod, just outside the 100-meter contour, the 40-meter temperature rose from 2.2° on March 24 (station 20088) to 3.78° on May 16 (station 20125), while the temperature at 100 meters hardly changed appreciably during this interval of nearly 8 weeks. Below that depth the water, which had cooled slightly from March to April, then warmed fractionally, so that the curves for March and May fall close together (fig. 3) at 140 meters (about 3°–4°). In the southwestern part of the basin, where no observations were taken in April, a similar difference obtains between records for May 17 and February 23, 1920, showing a warning of about 4° at the surface (7.22° to 8.33° in May, according to the locality), but with very little change at 100 meters.

Turning now to the opposite side of the gulf, Mavor's (1923) tables show the central part of the Bay of Fundy warming only fractionally at any level from April 9 to May 4, 1917 (whole column then between 1.9° and 2.8°), but then more rapidly to 8.18° at the surface, 4.68° at 30 meters, and 3.92° at 100 meters on June 15.

Assuming, from the character of the winters preceding, that the mean temperature at 40 meters ranged about 1° lower at the beginning of spring in 1920 than in 1915, the difference between the April and May readings, just summarized, suggests that this level normally warms by about 1° during the interval from mid-April to mid-May in the parts of the gulf where the change is most rapid.

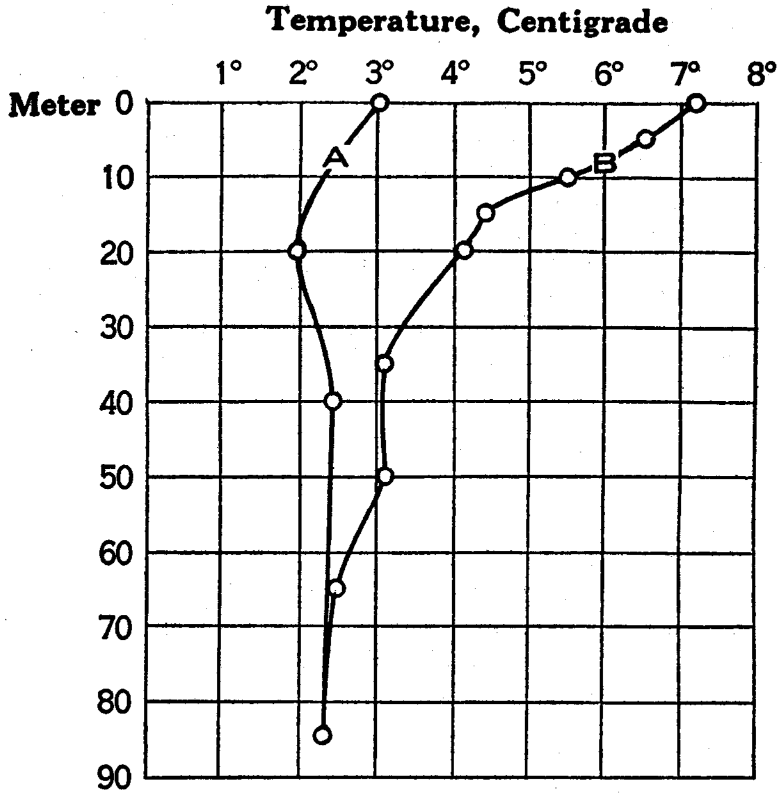

FIG. 33.—Vertical distribution of temperature in Ipswich Bay on April 9, 1920 (A, station 20092), and on May 7 and 8, 1920 (B, station 20122)

Taking the open gulf as a whole, the 100-meter readings for April, 1920 (a cold year), so closely reproduced the May readings for 1915 (a warm year)[18] that the temperature of the mid-depths may be described as virtually stationary during this part of the spring.

As the result of the two contrasting processes—vernal warming in the western side of the gulf and the inflow of cold water into the eastern—the regional distribution

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[18] Maximum divergence at this level, for pairs of stations, was only from 3° in the western basin on Apr. 18, 1920, station 20115, to 4.8° on May 4, 1915 ,station 10267.

of temperature at the 40-meter level alters from April (fig. 24) to mid-May (fig. 34) by a shift of the coldest area (1.58° to 2.1° in April, 1920; 3° to 3.25° in May, 1915) from the western and northwestern sides of the gulf to the eastern side. Similarly, the warmest center shifts from the eastern arm of the basin, where the April readings were highest in 1920, to the western, with the coastal sector from Massachusetts Bay to Cape Elizabeth (4.5° to 5.1°, May 4 to 14, 1915), with about equal temperatures along the southwestern edge of Georges Bank (5.4° to 5.6° on May 17, 1920, stations 20128 and 20129).

The mid-stratum of the gulf, as illustrated by the 100-meter level, continues through May as regionally uniform in temperature as it is in April (fig. 25), with an extreme recorded range of only 2.45° within the gulf for the two years 1915 and 1920 (2.65°, Massachusetts Bay, station 20124, to 5.1° northeastern part of the basin, station 10273) and slightly warmer (7.5°) along the southwestern slope of Georges Bank (station 20129). Within the basin of the gulf the 100-meter readings for May have been highest (4.4° to 5.1°) in the central and northeastern parts, lowest in the western (2.6° to 3.5°) and eastern sides (about 4°). This last reading perhaps reflects the chilling effect of the Nova Scotian current from above; but there is no reason to suppose that the latter influences the spring temperature much deeper than this, because the 150-meter readings for March 2 and 23, for April 17, 1920, and for May 6, 1915, all fall within 0.2° of one another (about 5° in temperature) in the eastern side, and are nearly as uniform over the gulf, generally, for all the May cruises, as appears from the following table:

1915		1919		1920	
Station	Approximate temperature	Station	Temperature	Station	Temperature
	° C.		° C.		° C.
10267	5.2	Ice patrol 20[1]	4.35	20125[2]	4.04
10268	5	Ice patrol 21	4.4	20126	4
10269	5.1			20127[1]	3.8
10270	5				
10273	4.98				
10278	3.5				

[1] At 146 meters.

[2] At 140 meters.

Thus the open basin of the gulf may be described as virtually uniform in temperature from side to side at the 150-meter level in May, though the precise readings may be a degree or so warmer or colder from one year to the next. The readings at the four deepest stations for May, 1915, also fall within 0.2° of one another at 185 to 190 meters (5.6° to 5.9° at stations 10267, 10268, 10269, and 10270).

The graphs for individual stations (figs. 3 to 11) show that in May (as is the case throughout the spring) the horizontal uniformity in temperature in the deep strata of the gulf usually is associated with a considerable rise in temperature with increasing depth, from the 50 to 100 meter level downward. As an example, I may cite a station off Cape Ann, occupied on May 4, 1915 (station 10267), when the 130-meter reading was 4.69°, with 6.59° at 260 meters depth. During the month the 200-meter level has averaged slightly warmer than the 100-meter level in the open basin of the gulf. In the Bay of Fundy, however, access to which for the inflowing bottom drift is hindered by the contour of the sea floor (p. 691), the temperature was virtually uniform from the 75-meter level downward on May 10, 1918 (about 2°), while in 1917 it was slightly lower (2.11°) at 175 meters than at 75 to 100 meters (2.2° to 2.8°) on the 4th of the month (Mavor, 1923). The deep sink inclosed by Jeffreys Ledge (recalling the Bay of Fundy in the contour of its floor, though smaller in area) was likewise nearly uniform in temperature from 100 meters (3.45°) down to 175 meters (3.7°) on May 14, 1915 (station 10278).

Whether the bottom water of the gulf basin cools or warms slightly from April through May, or whether the temperature remains virtually constant there, depends on the pulses just discussed (p. 555) and on the quantity and temperature of water brought in by them. If the inward drift over the bottom continues comparatively constant, little or no change is to be expected in the bottom temperature. If, however, the flow slackens or ceases, vertical circulation, from which no part of the gulf is free, will tend to equalize the temperature vertically; that is, to cool the deepest water while warming the overlying stata as they mix together. A pair of stations in the southwestern part of the basin for February and May, 1920, illustrate just this change, the slight rise in temperature with increasing depth from 100 meters downward to bottom in 150 meters, which was recorded for February 23 (station 20048), giving place to perfect vertical homogeneity by May (station 20127), while the 140 to 150 meter level cooled from 4.87° to 3·8° and the 100-meter level warmed from 3.54° to 3.8° during the interval.

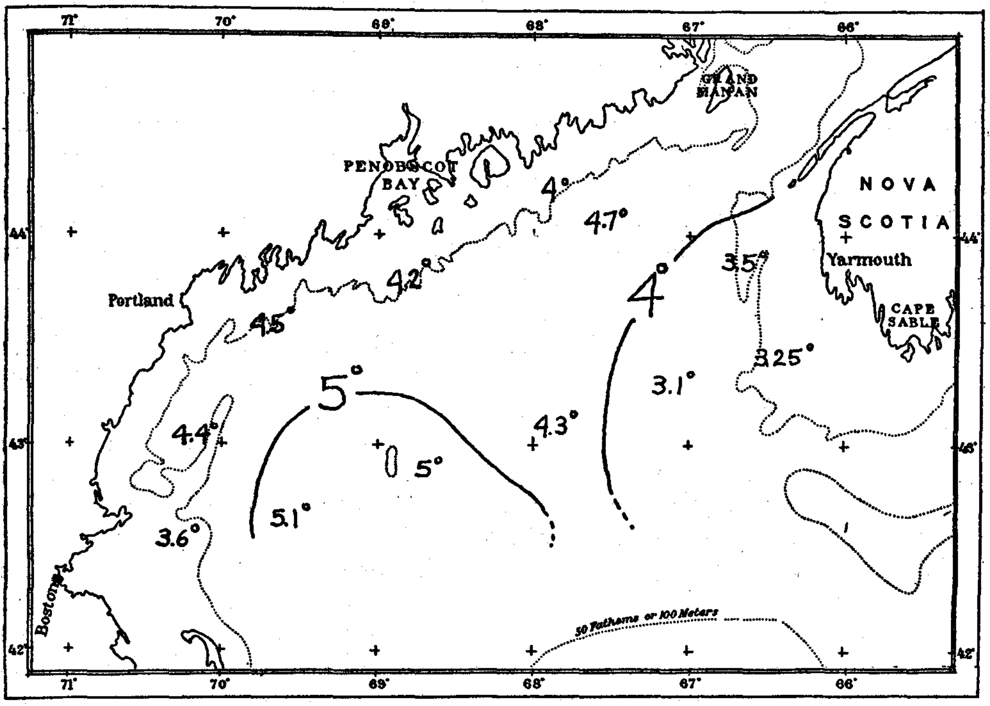

FIG. 34.—Temperature at a depth of 40 meters, May 4 to 14, 1915

The spacial distribution of temperature in May may be illustrated in a more connected way by three west-east profiles of the gulf—the first for April 28, 1919 (fig. 35), the second for May 4 to 7, 1915 (fig. 36), and the third for May 29 to 30, 1919 (fig. 37).

The first of these is interesting chiefly as it outlines the extension of the cold Nova Scotian current into the eastern side of the gulf, indenting like a shelf into the warmer water of the basin (isotherm for 4°, fig. 35). Water almost equally cold, washing the slope of Cape Cod at 60 to 120 meters in the opposite side of the profile, is reminiscent of the previous winter's cooling *in situ;* and the definite separation of these two cold masses by slightly higher temperatures in the central part of the basin deserves emphasis. Unfortunately no readings were taken deep enough in the basin to show what relationship the temperature of the bottom stratum bore to that of the mid depths at the time. So far as they go, however, they point to a homogeneous state at depths greater than 100 meters.

Although the May profile for 1915 (fig. 36) was run only a week later in date, the presence of a lenticular mass of 5° to 6° water over the western part of the basin, with maximum thickness of about 50 meters, illustrates a considerable advance in the seasonal cycle, reflecting the penetration of solar heat downward from the surface into the underlying water. Below it the cold coastal band that skirts the western side of the gulf earlier in the spring (the product of local chilling) is still represented at the mouth of Massachusetts Bay by temperatures of 3.5° to 4° at depths greater than 20 meters.

Whether the cold water of Nova Scotian origin in the eastern side of the gulf assumed a shelflike outline earlier in that particular spring, as it certainly did in 1919, is not known. If so, its tip had been eaten away by mixture with the surrounding water until its limiting isotherm (4°) had come to assume the more nearly vertical course shown on the profile (fig. 36). In actual temperature, however, this cold water mass was very nearly the same in 1915 as the ice patrol found it in 1919, one of the many illustrations that might be cited of the surprising constancy of the gulf in temperature from year to year. The presence of appreciably warmer (4° to 5°) water below it in both these years illustrates how strictly the inflow past Cape Sable into the gulf is confined to the upper stratum above the 100 to 120 meter level, a phenomenon resulting from the distribution of density in this side of the gulf (p. 946). As a consequence, the surface is the coldest level there in May, or at least the lowest readings will be had only a few meters down.

Figure 37 illustrates still a later stage in the thermal cycle, the Nova Scotian current having slackened and the two cold water masses that hug the two sides of the gulf earlier in the season having merged into the general stratum of minimum temperature (4° to 5°) at the 50 to 120 meter level. Vernal warming is illustrated further on this profile by a rise in the temperature of the upper 10 meters from about 5° at the end of April (5° to 6° on May 4 to 6, 1915) to 8° to 9°. In the deeps of the gulf a rise in temperature from about 4.5° to 5.6° to 6° during the preceding four weeks (cf. fig. 37 with fig. 35) is evidence of a considerable movement of slope water through the Eastern Channel into the gulf during the interval. However, the nearly horizontal course of the isotherm for 5 degrees across the basin on May 28 (fig. 37),

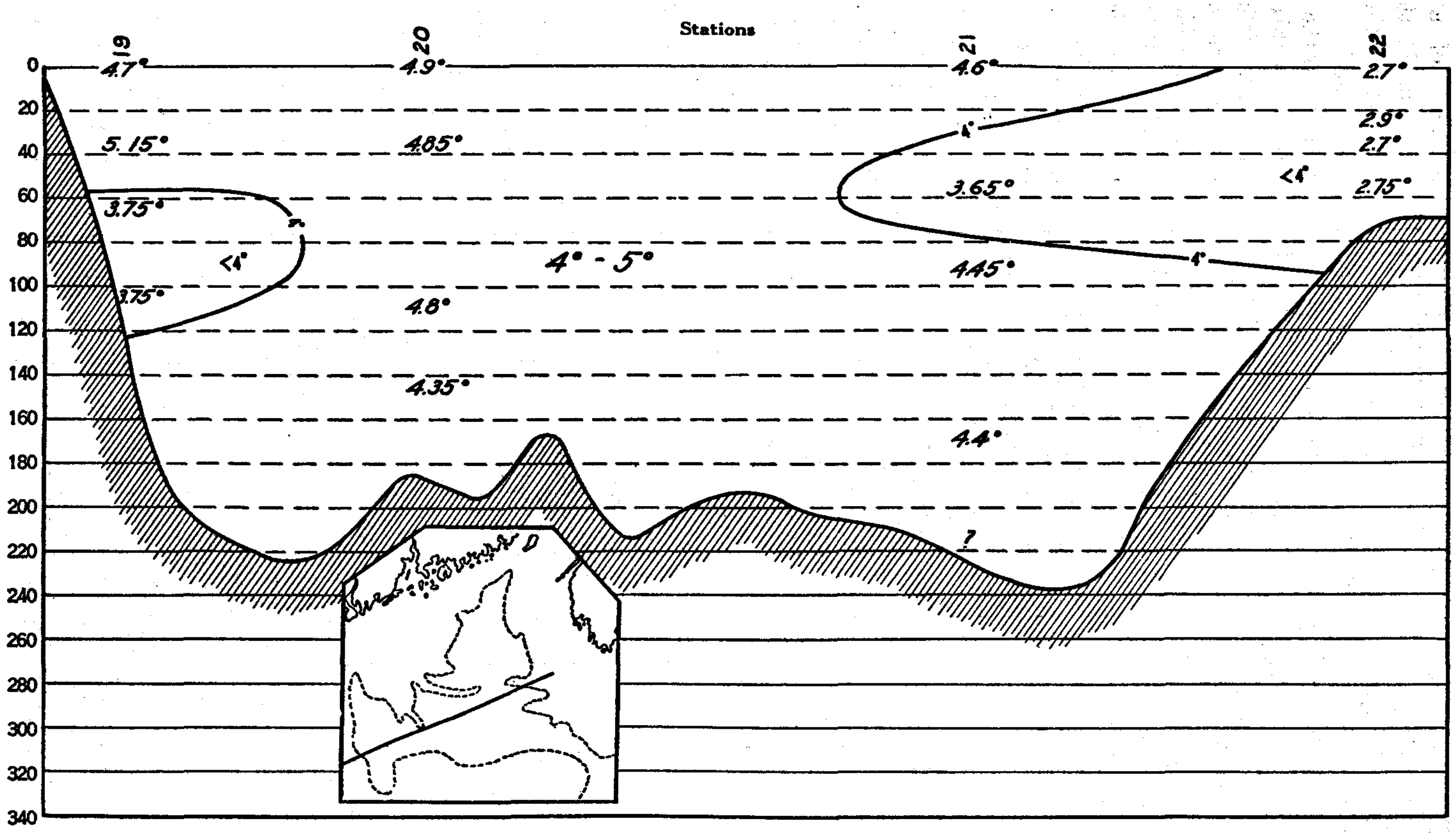

FIG. 35.—Temperature profile from a point a few miles off Cape Cod to German Bank, April 28, 1919 (ice patrol stations 19 to 22)

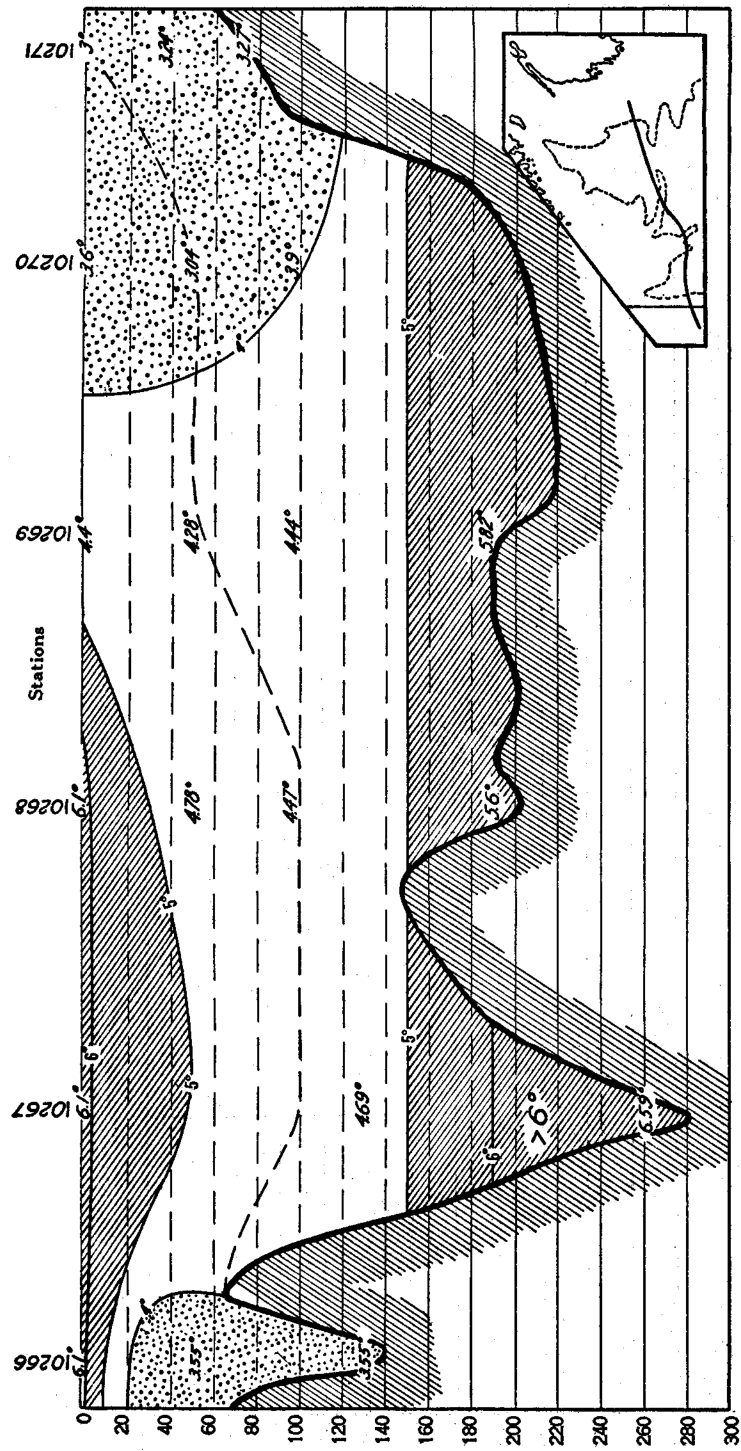

Fig. 36.—Temperature profile crossing the gulf from the mouth of Massachusetts Bay to German Bank for May 4 to 7, 1915

evidence of a static condition in the bottom water rather than one of active circulation, marks the precise date when this profile was run as falling between two of the pulses by which this indraft is believed to progress (p. 558), not as coinciding with one of them. Whether such a pulse annually succeeds the slackening of the Nova Scotian current remains to be learned, but this is not unlikely.

In 1920 the general increase in temperature that involves the gulf proper and the western part of its offshore rim from April to May, did not extend to the seaward slope of the latter. There, on the contrary, a change of the reverse order took place from about the 40-meter level right down to the bottom in 150 to 200 meters (fig. 38), illustrated by a decrease in the bottom temperature from 11.5° on February 22 (station 20045, 150 meters) to 8.28° on May 17 (station 20129, 160 meters). Accompanied, as it was, by a corresponding freshening at the bottom, this cooling is clear evidence that the warm, highly saline oceanic water that bathed this part of the slope in February, as it usually does in summer (p. 617), had receded offshore by May. Lacking data farther eastward along the slope for this season, it is impossible to state the precise cause of this event further than that it probably represented a dynamic alteration (p. 936) rather than a direct extension of Nova Scotian water in this direction (p. 825).

Whatever its cause, however, the fact that so great a chilling of the bottom water undoubtedly did occur in just this location in 1920 (and may, perhaps, every spring) is of great interest biologically, as events of this sort necessarily limit the permanent bottom dwellers of the eastern part of the so-called "warm zone" to such animals as can survive temperatures as low as 7° to 8°. Unfortunately no readings were taken there during the only spring (that of 1884) when a serious mortality is known to have taken place among its inhabitants—invertebrates as well as fishes (notably the tilefish)—but in very cold years the temperature there may fall several degrees lower, perhaps, than happened in 1920. Tentatively, mid May may be set as the coldest season on bottom along this part of the continental slope—three months later than in the inner waters of the Gulf of Maine.

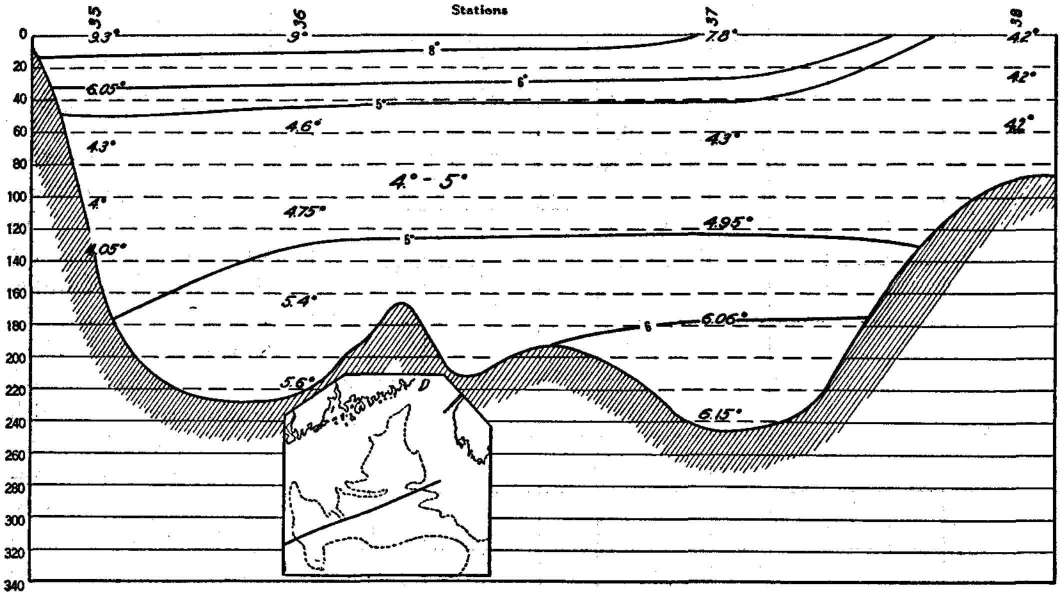

FIG. 37.—Temperature profile from a point a few miles off Cape Cod to German Bank, for May 29 and 30, 1919 (ice patrol stations 35 to 38)

JUNE

I am not able to present as satisfactory a thermal picture of the gulf for June as for the spring, no measurements of temperature having been made in the western side of the basin, along shore between Cape Ann and Cape Elizabeth, nor on Georges Bank during that month. On the other hand, our June cruise of 1915 led far enough east past Cape Sable to cross-cut the Nova Scotian current before it passes that promontory. The *Fish Hawk*, also, made a general survey of Massachusetts and Cape Cod Bays on June 16 and 17 in 1925. A few temperatures were taken by the *Halcyon* near Gloucester on the 6th in 1924, in the Nantucket Shoals region during the first half of the month in 1925, and Dawson (1922) also took a considerable number of June readings along Nova Scotia in 1904 and 1907.

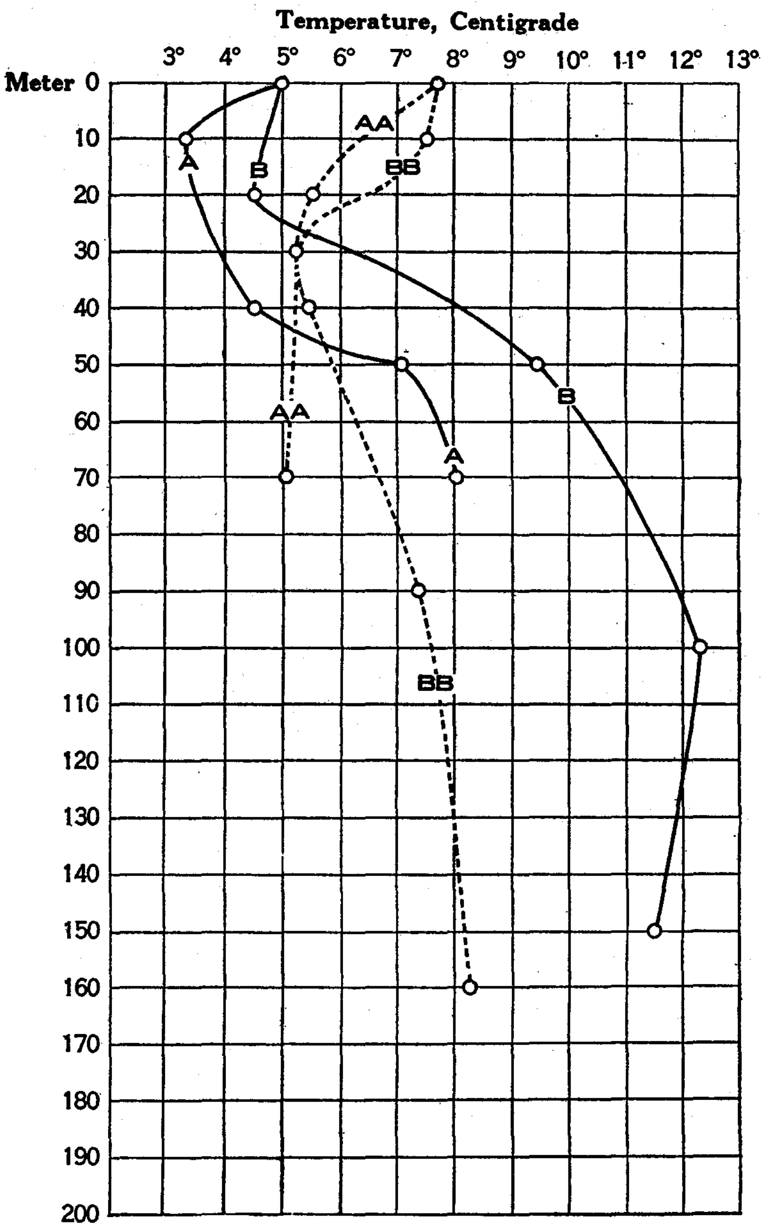

FIG. 38.—Vertical distribution of temperature on the southwestern slope of Georges Bank to show cooling of the bottom water, but warming at the surface, from February to May, 1920. A and B, February 22 (stations 20046 and 20045); AA and BB, May 17 (stations 20128 and 20129)

RATE OF WARMING

Progressive warming is to be expected, of course, over the whole area throughout the month of June. Thus, the surface had warmed to 10.56° at a station 8 miles off Gloucester on the 6th in 1924, and to 12.1°–15.2° over Massachusetts Bay generally by the 16th or 17th in 1925, an average change of about 5 degrees since May 20 to 22. At the 20-meter level these mid-June temperatures averaged about 7.8° (18 stations), contrasting with about 5.5° in May (p. 564), with the readings for June 6, 1924 (6.2°) intermediate, as the date would suggest. These Massachusetts Bay stations for 1925 also illustrate interesting regional differences in the rate at which heat penetrates downward into the water during the late spring and early days of summer, depending chiefly, it would seem, on differences in the extent to which the water is stirred by the tides and on the freedom of interchange of water between the coastal zone and offshore—perhaps to some degree on upwellings.

In midwinter the Plymouth shore and Cape Cod Bay to the southward see winter chilling more rapid than in any other part of the Massachusetts Bay region (fig. 81). With the advance of spring, however, the regional relationship is reversed, so that by May we find the surface water warmest in Cape Cod Bay (p. 557, fig. 28). During the last week of that month, however, and the first half of June, the western side of Massachusetts Bay had caught up with Cape Cod Bay in the progression of temperature, so that all this area (inclosed by the isotherm for 15° on fig. 39) was now nearly uniform (15 to 15.2°) in surface temperature, except for one station off Plymouth Harbor, where vertical circulation of some sort was responsible for a slightly lower reading (14.43°).

Considerably lower surface temperatures (12.1° to 13.3°), right across at the mouth of the bay, show that the offshore waters had lagged behind the coastal belt in warming; and still lower readings (12° to 13°), along the north shore of the bay deserve emphasis because the 20-meter level was warmest here, coldest at the mouth of the bay, and with a rather surprisingly wide range in temperature (12.03° to 4.56°) from station to station. Active vertical stirring is clearly responsible by bringing the upper 20 meters within the immediate effect of the sun's rays, to warm nearly uniformly along the northern shore. At the same time it is probable that the warming of the upper stratum in this particular region is forwarded during June by a more or less constant drift of the surface water—already warmed to 12° to 14° temperature—around Cape Ann and westward into the bay. Consequently, a somewhat higher mean temperature for the upper 20 meters may be expected to prevail along its northern shore than in its central parts in June, just as was actually recorded in that month in 1925 (*Fish Hawk* cruise 14, stations 35 to 37), instead of a lower mean temperature, as is the case later in the summer.

More rapid warming of the surface along the Plymouth shore and in Cape Cod Bay, but a slower rise in temperature at 20 meters, points to a less active overturning by the tides; and the fact that the surface and 20-meter readings both averaged 2° to 3° higher there than over the deep sink off Gloucester (*Fish Hawk* station 31) is evidence that the interchange of water between the open basin of the gulf, on the one hand, and the western and southern parts of Massachusetts and Cape Cod Bays, on the other, had been so slow for some weeks previous that the latter had acted as a more or less isolated center of local warming. On the other hand, the low temperatures (5 to 6°) at the 20-meter level along the eastern side of Stellwagen Bank, at the mouth of the bay, point to a certain amount of upwelling over the slope of the latter, bringing up cold water from greater depths offshore.

These regional differences in the June temperatures for 1925 are smoothed out over the Massachusetts Bay region with increasing depths. At 40 meters, for example, the extreme range of temperature was then only from about 3.5° to about 6.1°, with the mouth of the bay uniformly 4° to 4.5°, and the 40-meter temperature (about 3.6°) off Gloucester for the 6th of the month, for 1924 (station 10653), falls within this range. At 75 to 94 meters the temperatures of Massachusetts Bay were also about the same in 1924 (3.13°, station 10653) as in 1925 (3.97° and 4.04° at *Fish Hawk* stations 30 and 32).

Out in the open basin, off Cape Ann, the surface warmed from 6.1° on May 4, 1915 (station 10267), to 13.6° on June 26 (station 10299), or at about the same rate as in Massachusetts Bay in 1925. The 40-meter temperature, however, rose by only 1.5° during the interval (from about 5.2° to about 6.8°), while virtually no change took place at 90 meters or deeper (fig. 5). It is probable, also, that the seasonal

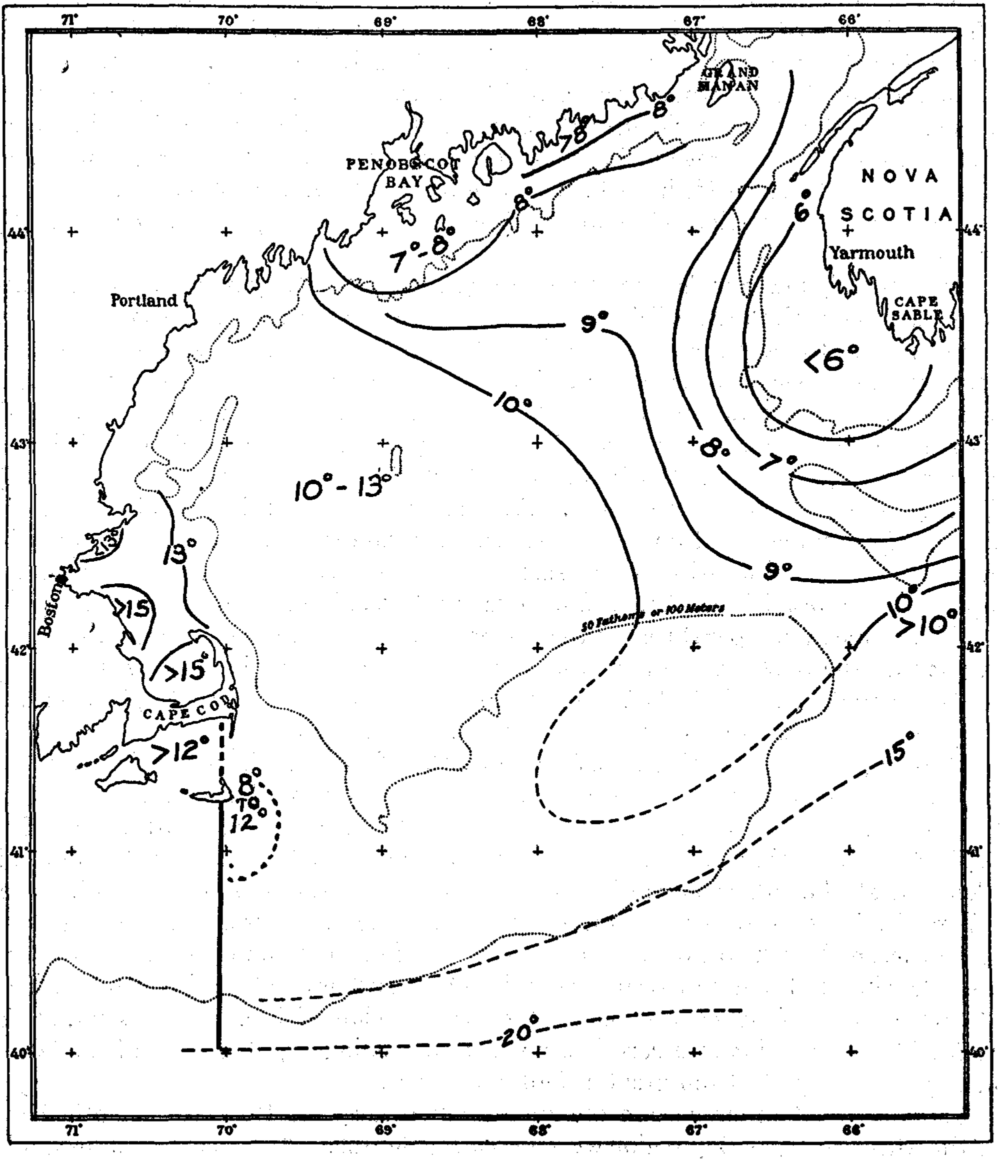

FIG. 39.—Surface temperature in mid-June from all available sources. The dotted curves are based on Dixon's (1901) tabulation

succession illustrated by these two stations is characteristic of that side of the basin in general.

No observations have been taken in the western side of the gulf in June, or on Nantucket Shoals, on the cruises of the Bureau of Fisheries' vessels, except those just mentioned; but the daily data tabulated by Rathbun (1887) for several lighthouses and lightships partially fill the gap for the coast sector between Cape Ann and the Mount Desert region, and are consistent with the serials taken of late years in the northeastern part of the gulf, in the Bay of Fundy, and in Massachusetts Bay.

Approximate temperatures (°C.) at the surface on June 15, from Rathbun's (1887) tables[1]

Locality	1881	1882	1883	1884	1885	Average
Pollock Rip lightship	14.2	9.7	12.2	11.7	10.6	11.7
Thatchers Island (Cape Ann) light	13.2	------	12.2	------	------	12.7
Boon Island light	10	8.3	10.6	11.4	10.3	10.1
Seguin Island light	9.8	10.9	11.9	11.4	9.4	10.7
Matinicus Rock light	8.3	8.3	7.2	8.3	7.5	7.9
Petit Manan light	7.6	8.9	10.3	10.6	10.1	9.5

[1] Given only to nearest 0.1°.

The 10-day averages for Gloucester and Boothbay for 1920 (figs. 29 and 30) show that the water warms only slightly faster in inclosed locations of this sort than off the open coast (compare 13° at Gloucester and about 12° at Boothbay on June 15 with Rathbun's record of 12° to 13° at Thatchers Island, off Cape Ann, and of 9° to 11° at Seguin Island. A temperature about 3 degrees lower at Matinicus Rock, at the mouth of Penobscot Bay, than at Seguin Island, some 34 miles along the coast to the westward, probably reflects some local retardation of vernal warming by the spring freshets from the Penobscot River. Conversely, the comparatively high temperature at Petit Manan suggests that readings as warm as 10° are to be expected by June 15 after a few days of warm weather, in sheltered locations along shore in shallow water, to the east as well as west of Mount Desert. In fact, Doctor McMurrich records almost as high surface temperatures (9° to 9.5°) at St. Andrews by June 15 in 1916. Lubec Narrows, however, open to the Grand Manan Channel and with a great volume of water rushing through on every tide, had warmed to only about 6° by this date in 1920 (fig. 31).

Earlier in the season, and up to mid May, the vertical distribution of temperature in the upper 150 meters or so is of one type throughout the inner waters of the gulf, though the actual values differ slightly from station to station. During late May and June, however, very important differences develop between the state just described for the western side of the gulf (where the rapid warming of the upper stratum by the sun, coupled with the sudden establishment of a high degree of vertical stability, causes the development of a steep temperature gradient in the upper 40 to 50 meters, overlying water more nearly homogeneous) and the northeastern part of the gulf, where more active stirring by the tides spreads the warmth received from the sun through a thicker stratum of water. Furthermore, we find the rate of warming decreasing from west to east as we follow around the coast line of the gulf, even after this regional difference in the downward dispersal of the heat received has been allowed for. Thus, the surface had warmed only from 5° on May

12 (station 10276) to 7.8° on June 14 (station 10287) off Penobscot Bay; the 40-meter level from 4.2° to about 5.8°, while the courses of the curves suggest that no appreciable change in the temperature of the water is to be expected at or below 80 meters off this part of the coast during the month of June.

In the immediate vicinity of Mount Desert Island the surface temperature rose by about 1° from May 10 to 11 (stations 10274 and 10275, 4.2° and 4.4°) to June 10 to 11 (stations 10283 and 10284, both 5.4°); but four days later surface readings of 7.5° to 8° were had at three stations (10285 to 10287) a few miles to the westward. The graphs (fig. 7) for these stations, as compared with May 10 (station 10274), show that the whole column, down to the bottom in 80 meters, warmed at a nearly equal rate there up to June 10, instead of most rapidly at the surface, as happens off Penobscot Bay and in the Massachusetts Bay region, no doubt because of the stronger tidal currents to the east than to the west of Penobscot Bay (p. 678).

Near Mount Desert Island this vertical stirring is sufficiently active to bring the whole column of water uniformly under the effect of the sun's rays during the early spring, resulting in the uniform rate of warming from surface to bottom just noted. During June, however, the surface receives heat so rapidly there, coupled with a corresponding freshening (p. 747), that the column is stabilized vertically, though the deeper layers are never so insulated here as in the less actively stirred waters to the west of Penobscot Bay and to the south of Cape Elizabeth.

In 1915 this establishment of stability in the Mount Desert region evidently fell between June 10 and June 15, because the surface warmed more rapidly there between these two dates (a change of about 2°) than it had during the preceding month, though the 30-meter and deeper temperatures rose by only about 0.2° meantime.

Data are not available for a general survey of the temperature of the Bay of Fundy for the month of June, but very considerable local differences in the rate of vernal warning are to be expected there during the early summer to correspond with regional differences in the activity with which the water is stirred by the violent tidal currents. The Grand Manan Channel stands at the one extreme, with the whole column of water warming uniformly, or nearly so, through June down to 100 meters, and correspondingly slowly at all depths. Thus, on June 4, 1915, the whole column of water in the western end of the channel abreast the north end of Grand Manan (station 10281; 80 meters) was about 4.5° in temperature, pointing to a rise of about 2° at all levels from the minimum of the preceding winter, and the channel continues homogeneous in temperature from surface to bottom into August (p. 599).

In the central parts of the Bay of Fundy, however, vernal warming essentially parallels the account just given for the Mount Desert region, with a similar seasonal relationship between successive monthly curves (fig. 40) constructed from Mavor's (1923; *Prince* station 3) records for the spring of 1917, though the actual temperatures differ somewhat at the two localities. Thus, this Fundy station warmed from 2.96° to 8.18° at the surface between May 4 and June 15; from 2.01° to 4.13° at 50 meters; from 1.87° to 3.92° at the 100-meter level; and from 1.75° to 2.08° at 150 meters;

so that the temperature curves for the two dates recall those off Mount Desert for May 10 and June 14, 1915, in their mutual relationship. A similar seasonal relationship also obtains between serials taken in the Fundy Deep near by on March 22, 1920 (station 20079), and June 10, 1915 (station 10282).

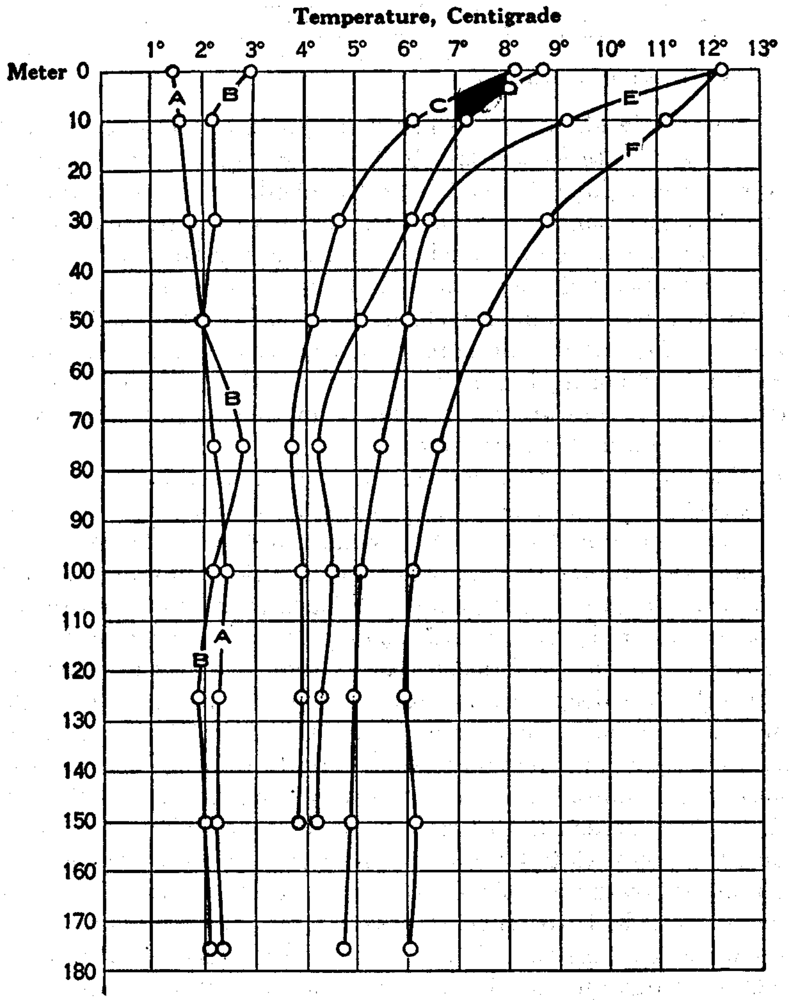

FIG. 40—Vertical distribution of temperature in the Bay of Fundy in 1917, from Mavor (1923, *Prince* station 3, 1916–17). A, February 28; B, May 4; C, June 15; D, July 4; E, July 31; F, September 4.

In 1917 the surface temperature had risen only to 8.68° at the *Prince* station by July 4 (Mavor, 1923, p. 375); the 50-meter level to 5.06°, the 100-meter level to 4.5°, and the 150-meter level to 4.21°; but warming either took place more rapidly in the Bay of Fundy in 1904, or the temperature did not fall so low there during the preceding winter, because Dawson (1922, p. 82, station F) found the deeper strata of the Fundy Deep about 2° warmer than this a week earlier in the season, as follows:

Serial temperatures (° C.) in Fundy Deep for June, 1904, after Dawson (1922)

Depth	June 23, 1904	June 29, 1904[1]	Depth	June 23, 1904	June 29, 1904[1]
Surface	8	11.1	27 meters	6.7	8.6
9 meters	7.5	9.7	55 meters	6.4	7.5
18 meters	7	9.4	91 meters	6.4	6.4

[1] Dawson's records are given to the nearest 0.5° F.

Surface water only about 4° warmer than the 50 to 60 meter level at these Bay of Fundy stations, as late as the last half of June, is an interesting contrast to the coastal sector between Cape Cod and Cape Elizabeth, where the surface temperature rises to 7° to 8° higher than 50 to 60 meter temperature by that season; nor does this regional divergence reach its maximum until late in summer (p. 596).

The most interesting phase of the June temperatures for 1915 is the light which they throw on the hydrographic cycle in the southeastern parts of the gulf. As stated above (p. 561), actual chilling takes place over the banks west of Nova Scotia, and out into the neighboring basin, from April to May, while the icy water of the Nova Scotian current is flowing into the gulf from the east past Cape Sable, although vernal warming is well under way elsewhere.

In 1915 this flow had become so weak during the last half of May (if it had not ceased altogether) that it no longer offset the normal tendency of the water to warm at this season. Consequently the temperature of the whole column of water on German Bank rose from about 3° on May 7 to about 6° on June 19 (station 10290). Unfortunately, the neighboring station in the basin (10270) was not revisited in June; but the surface a few miles northward also warmed from a temperature of 4° to 5° in mid May to 9.7° on June 19 (station 10288), though with a rate so rapidly decreasing with depth that the deep water, at 100 to 180 meters, was only 0.4° to 1° warmer on the later date than on the earlier one. As this rise of temperature in the deeps was accompanied by a corresponding rise in salinity (p. 755), it is to be credited to a renewed pulse in the inflow through the Eastern Channel, and 1919 seems to have been a still "earlier" season in this respect, as described above (p. 558).

Off Shelburne, only 25 to 30 miles to the eastward of Cape Sable, by contrast, the 50 to 75 meter stratum continued very cold next the coast (0.7° to 0.9°) until the last week of June in 1915 (Bigelow, 1917a, stations 10291 and 10292), and was only slightly warmer at the end of July of that year (Bjerkan, 1919) or in July, 1914 (station 10231). Consequently, it would not be surprising to find the water along western Nova Scotia temporarily chilled by a renewed pulse from this icy reservoir at any time during June, either at the surface or a few meters down. Serial readings taken off Yarmouth, also off Cape Sable, by Dawson in 1907 (1922, p. 82, stations M and S), show that some such event did take place that year, made evident by a drop in the bottom temperature (55 meters) in the offing of Yarmouth, Nova Scotia, from 4.7° on June 17 to 1.1° on June 25, although the surface water continued to rise in the normal seasonal advance.

Temperatures (°C.) 17 miles southwesterly from Cape Fourchu in 1907, from Dawson (1922, p. 82)

Depth	June 17	June 21	June 25
Surface	5.6	6.4	8.9
9 meters	5	6.1	6.9
18 meters	5	4.7	3.9
27 meters	4.7	4.7	2.8
55 meters	4.7	4.7	1.1

The source of this cold indraft is found near Cape Sable—by Dawson's records 10 miles south from Brazil Rock on the 26th and 27th, quoted below—which also shows an interesting variation in temperature at different stages of the tide.

Temperatures (°C.) 10 miles south of Brazil Rock (from Dawson)

Depth	June 26, high water	June 27, low water
Surface	8.6	7.8
9 meters	4.7	7.5
18 meters	2.8	4.7
27 meters	2.5	3.9
55 meters	1.4	1.9

It is probable that when belated overflows of the cold Nova Scotian water into the gulf do occur after early June they are of brief duration, for we have found no evidence of such an event later in the season on our recent cruises.

Dawson's June temperatures likewise afford an interesting illustration of the rate at which the surface water may be expected to warm along the Nova Scotian coast sector between Yarmouth and Cape Sable during the month of June. Thus, the surface there was 4.4° to 5° on the 7th of the month in 1904, though it had already risen to 6° at the mouth of Yarmouth Harbor by that date. In 1907 the surface was 5° to 6° in the offing of Yarmouth on the 11th to 15th; 6° to 7.8° on the 22d (warmest close in to the land); 6.5° to 8° to the eastward of Cape Sable by the end of that month; but the tide-swept region close to the cape was still only 4.2° to 5°, and this cold pool reappears on our charts for August (p. 592).

In 1915 the temperature of the surface water had risen to 10° over Browns Bank and the Eastern Channel (stations 10296 and 10297) by June 24 to 25, which is 3.5° cooler than the expectation for Massachusetts Bay at that date, and the water that filled the trough of the channel at depths greater than 100 meters was about 1 to 2 degrees warmer (7° to 8°) than on April 16, 1920 (station 20107). On Browns Bank, too, the temperature of the bottom water was about 4° higher at the June station than at the April station (stations 10296 and 20106), but the 40-meter reading was actually lower in June (2.8°)—colder, in fact, than any June reading in the inner parts of the Gulf of Maine. The presence of a cold mid stratum at this particular locality sandwiched between water of 7.36° on bottom at 80 meters, 10° at the surface, is unmistakable evidence of an extension of the cold Nova Scotian water from the eastward out over the bank, indenting into the higher temperatures that may be expected to prevail there earlier in the season. The profile run across the shelf abreast of Shelburne, Nova Scotia, the day before (stations 10291 to 10295, June 23 and 24, 1915) corroborates this apparent tendency for the cold Nova Scotian current to swing offshore abreast Cape Sable at the time, instead of flowing past the cape into the eastern side of the Gulf of Maine, as it does earlier in the season. This profile (fig. 41) lies outside the geographic limits of the present discussion; it will be enough, then, to point out that it cuts across a lenticular mass of water colder than 2°, occupying the whole breadth of the continental shelf at the 40 to 100 meter level, with a minimum reading of only 0.7° (station 10292, 50 and 75 meters) in the trough between the land and La Have Bank.

The high temperatures recorded for the Eastern Channel in June, 1915, prove Browns Bank the westerly boundary for the icy water at the time; but it may extend across the Eastern Channel to Georges Bank earlier in the month in some years, a question discussed below in connection with the July temperatures of the bank (p. 919).

Unfortunately, no temperatures have been taken below the surface on any part of Georges Bank in June. It is probable that the vernal expansion of the cold Nova Scotian current maintains temperatures lower than 10° on the eastern part of the bank until the first of the month, and Dickson (1901) so represents it on his chart of surface temperatures for June, 1897, contrasting with temperatures higher than 12° in the western side of the gulf, on the one hand, and outside the continental edge, on the other. July temperatures (p. 594), however, suggest that the surface on the western end of the bank may be expected to warm to 10° to 11° by mid June, except locally, where strong tidal currents and rips sweep around its shoalest portions. Considerable variations develop in the temperature gradient on Nantucket Shoals by that month, however, according to the local activity of the tidal stirring, for the *Halcyon* found the temperatures almost exactly the same on bottom in about 30 meters depth (8.3°) as at the surface near Round Shoal on June 7, 1925, but the bottom more than 5° colder than the surface[19] in water of about 40 meters depth only 6 miles to the eastward.

Judging from daily readings made at Nantucket lightship in the years 1881 to 1885 (Rathbun, 1887), and from the *Halcyon* temperatures just cited, surface temperatures of 10° to 12° (varying somewhat from year to year) are to be expected in the Nantucket Shoals region generally by the middle of June.

GENERAL DISTRIBUTION OF TEMPERATURE

A graphic picture of the June state for the gulf as a whole results from combining the June stations for the various years (fig. 39). Unfortunately, the observations not only include possible annual differences, but cover too long a space in time for this surface chart to be as satisfactory as might be wished at a season when the water is absorbing heat from the sun as rapidly as happens through June. It will serve, however, as an indication of the regional distribution and approximate values that may be expected in various parts of the gulf at the middle of the month. Its feature of chief interest is that the temperature is higher in the western side than

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[19] Surface 11.7°; bottom 6.4°.

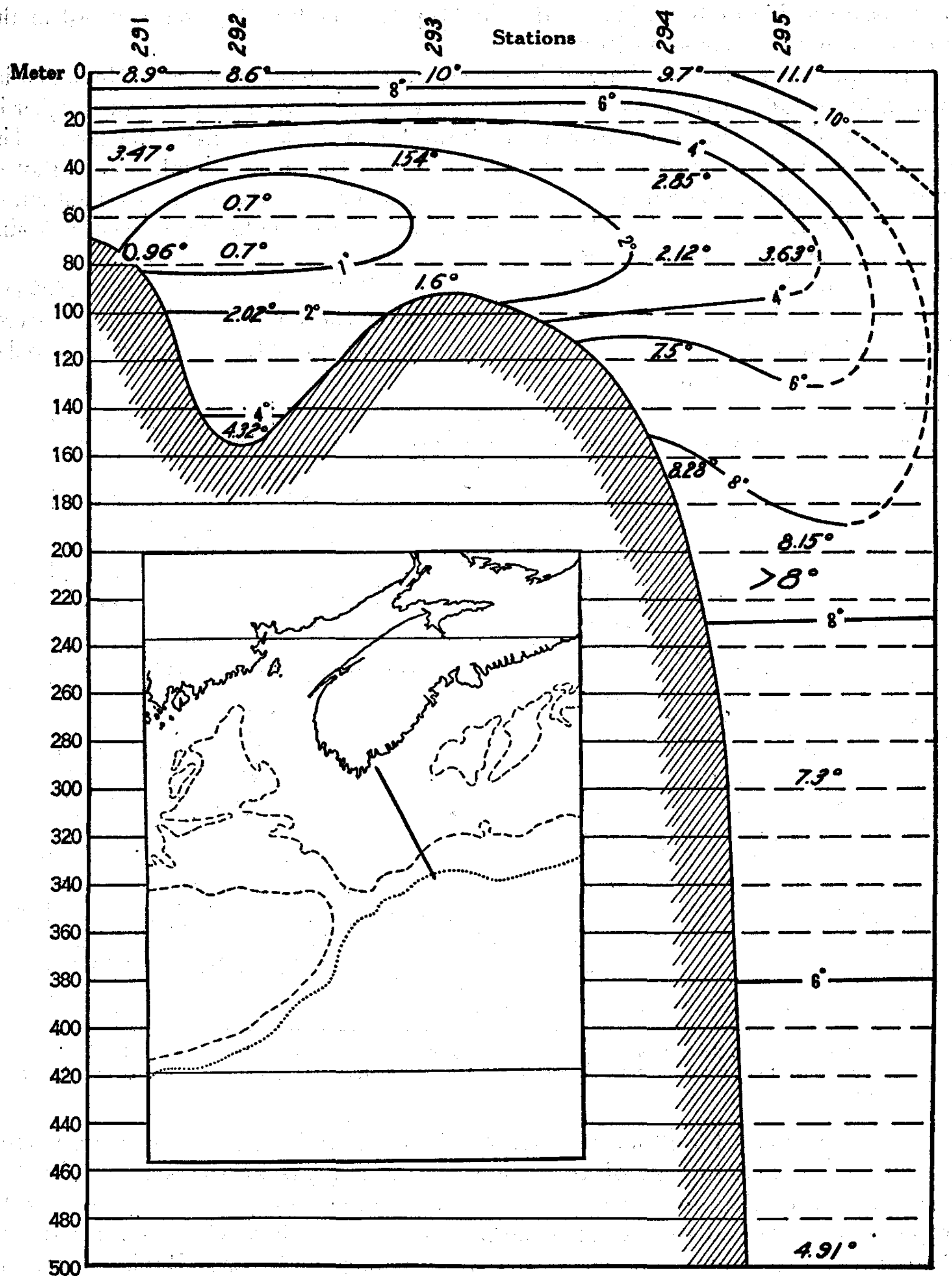

FIG. 41.—Temperature profile running southward from the vicinity of Shelburne, Nova Scotia, to the continental slope, for June 23 and 24, 1915

in the eastern side in June, just as it is in May (p. 556, fig. 27), and warmest in the inner part of Massachusetts Bay.

In June the surface of the gulf is coldest over the shallows west of Nova Scotia, with rather a sudden transition from surface temperatures of 8° to 9° and higher in the eastern side of the basin to readings lower than 7° to 8° next the land. The comparatively warm core (8° to 9°) extending up the deep trough of the Bay of Fundy, outlined by the curve for 8° on this surface chart, also deserves mention, as does the slightly cooler zone (7° to 8°) extending westward along the coast of Maine across the mouth of Penobscot Bay.

In the offshore side of the picture, Dickson's (1901) data for the years 1896 and 1897 locate the isotherm for 15° as following along the continental edge of Georges Bank, with surface water of 20° separated from the edge of the continent by a wedge of cooler water increasing in breadth from west to east.

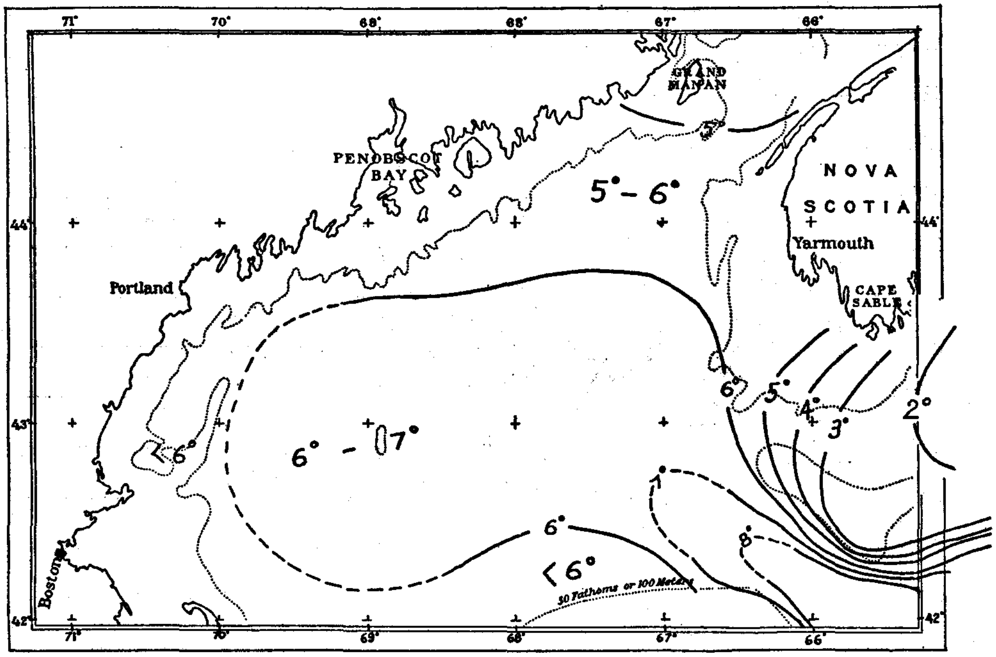

FIG. 42.—Temperature of the eastern side of the gulf at a depth of 40 meters, last half of June, 1915. The Bay of Fundy temperature is according to Mavor (1923); the temperatures along western Nova Scotia are from Dawson (1922)

The June chart for 40 meters (fig. 42) shows a gradation in temperature across the gulf from west to east of the same sort as appears at the surface (fig. 39). The influence of the Nova Scotian current on temperature at the 40-meter level is graphically illustrated by an expansion of water colder than 3° from the coast off Shelburne, Nova Scotia, out across the western part of Browns Bank, contrasting with higher temperatures (5° to 6°) on German Bank and along western Nova Scotia.

The most interesting feature of this 40-meter chart is the sudden transition between the cold water on Browns Bank to the much higher temperature (8.2°) in the Eastern Channel (a horizontal dislocation of 5° in a distance of only about 15 miles) and its demonstration that the latter is clearly a tonguelike intrusion from offshore. The records are not sufficient to outline exactly how far 7°-water then penetrated the southeastern part of the gulf; but the temperatures at such of the stations as lie in the course usually followed by the inflowing current (6.3° and 6.1° at 40 meters at stations 10288 and 10299) suggest that readings as high as 7° would not have been found farther west in the basin than is outlined on the chart at any time during June, 1915. Undoubtedly, however, wide fluctuations occur from year to year in this respect.

If the data for the two years 1915 and 1925 can justly be combined, as seems allowable because the preceding winters were not unusually severe, slightly higher temperatures are to be expected over the eastern and central parts of the basin generally than either in the northeastern corner of the gulf (including the Bay of Fundy), on the one hand (40-meter level about 4° to 5°), or off Massachusetts Bay, on the other, where the *Fish Hawk* recorded 40-meter temperatures of 3.5° to 4.5° at most of her mid June stations in 1925. A 50-meter reading of 5.18° in the southern side of the basin as late as June 25, 1915 (station 10298), suggests that the 6° to 7° water then takes the form of a pool, as it is shown in the chart, entirely surrounded by slightly lower temperatures except for its connection with still warmer water outside the edge of the continent, via the Eastern Channel. A regional distribution of temperature of this sort is interesting as evidence that the influence of the indraft through the Eastern Channel may raise the 40-meter temperature of the central parts of the gulf slightly higher in late June than the figure (4° to 5°) to which solar warming, unassisted, would bring it by that date.

At a depth of 100 meters (fig. 43) the isotherm for 5° shows a tendency on the part of this indraft to follow the eastern slope of the basin and to eddy to the westward around its northern side, but this drift seems not to have been active between the dates covered by this cruise (June 10 to 26) because not as clearly outlined as in March, 1920 (fig 13), but showing a gradation in temperature from 8° in the Eastern Channel to 5° at the mouth of the Bay of Fundy. Had water been flowing actively inward through the channel at the time, a uniformly high temperature (7° to 8°) naturally would have resulted over a considerable area in the eastern side of the gulf. A transition of the opposite sort along the Northern Channel, from 6° to 7° at its western end to 2° to 3° at its eastern end, is evidence equally clear that no general movement of the water was taking place through this trough, either westward into the gulf or vice versa.

Unfortunately, no data are available on the subsurface temperatures along the seaward slope of Georges Bank for June, but our Shelburne profile for June 23, 1915 (fig. 41), showed the warmest (8°) bottom water separated from the edge of the bank by a much cooler (about 4°) wedge at 100–120 meters, as seems always to be the case to the eastward of the Eastern Channel.

The temperature of the bottom water in the deeps of the gulf is always interesting because of the light it throws on the inward pulses (p. 922). During the last half of June, 1915, this was fractionally warmer than 6° in the eastern and south central parts of the basin at depths greater than 175 to 185 meters (stations 10288 and 10298), underlying a cooler stratum (4° to 5°) at 50 to 150 meters; and although no record was obtained of the bottom temperature in the western arm of the basin on this cruise, the presence of 6°-water there on May 4 (p. 566) at depths greater than 225 to 230 meters, and again on August 31 of the same year (station 10307), makes it almost certain that this was also the case in June.

The relationship which this warm bottom stratum bears to the cooler water above it and to the indraft from outside the edge of the continent, is made more graphic by the accompanying profile, running from the Eastern Channel westward and inward along the basin (fig. 44).[20] Obstructed on the north by the topography of the sea floor, this warm bottom water reaches the western part of the basin off Cape Ann via the southern branch of the trough, a route that entails its rising over the intervening ridge to within 190 to 200 meters of the surface.

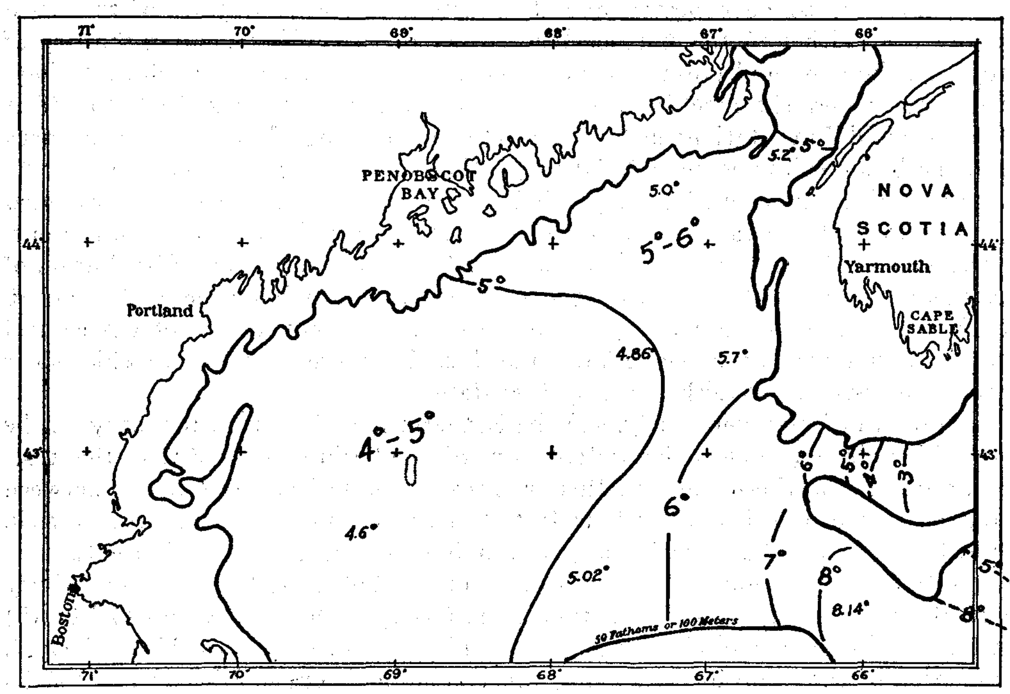

FIG. 43.—Temperature at a depth of 100 meters, last half of June, 1915. (The Bay of Fundy is according to Mavor, 1923.)

It is probable that overflows of this sort are intermittent—frequent enough, however, to maintain the bottom temperature of the western bowl fractionally above 6° for most of the year. The greater thickness of the warm bottom stratum in the southeastern side of the basin (into which the Eastern Channel opens) than elsewhere in the gulf corresponds to the proximity of the source of supply; and it is not unlikely that bottom temperatures of 7° or higher would have been found there at the end of June had readings been taken in depths greater than 275 to 300 meters.

In horizontal plan the bottom water of 6° takes the form of a Y, following the outlines of the trough of the gulf; its approximate outlines for May and June, 1915, are shown in the accompanying chart (fig. 45).

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[20] The deepest readings in the western side of the basin are borrowed from the May station (10267).

JULY AND AUGUST

The vessels of the Bureau of Fisheries have taken a large number of observations within the gulf during the months of July and August since 1912. July and August temperatures have been recorded in various parts of the Bay of Fundy region under the auspices of the Biological Board of Canada over a series of years.[21] The tidal survey of Canada (Dawson, 1905 and 1922) likewise has gathered a considerable body of thermal information for the Fundian region and along the Nova Scotian side of the open Gulf of Maine. With such a wealth of material available, the chief difficulty in establishing the normal midsummer state of the gulf has been to appraise the importance of the annual and sporadic fluctuations that confuse the record.

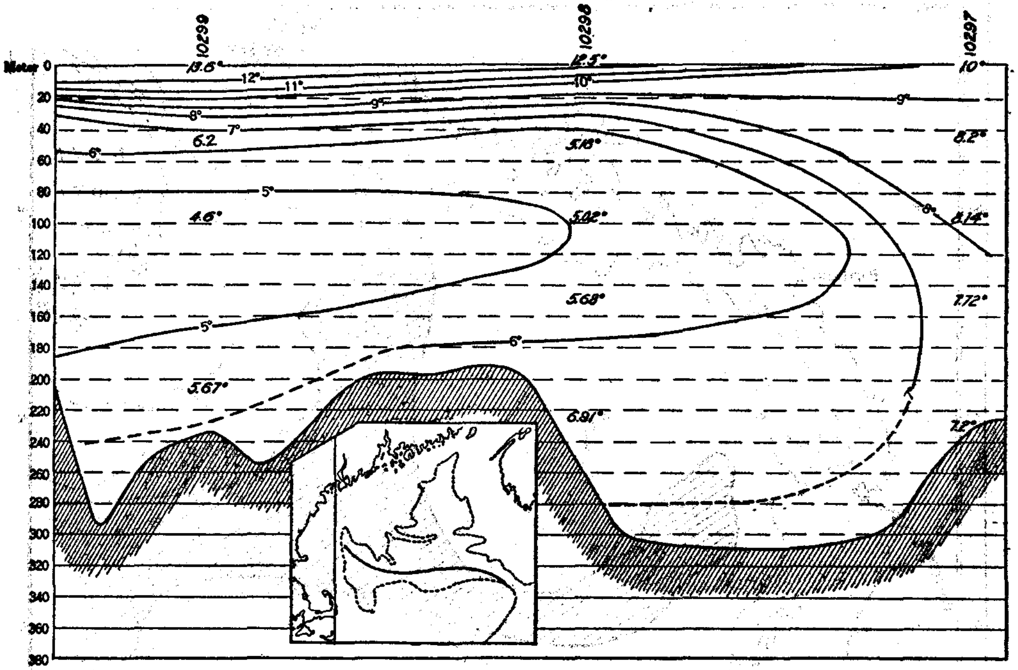

FIG. 44.—Temperature profile running easterly from the basin off Cape Ann along the trough of the gulf to the Eastern Channel for June 25 and 26, 1915

SURFACE

As the result of continued warming by the sun, the surface of all parts of the gulf is considerably warmer in July and August than it is in June, in most years rising nearly to its maximum by the last week of July over most of the gulf. The graphs for Gloucester and Boothbay Harbors (figs. 29 and 30) show that in inclosed situations of this sort the surface water is warmest then, mirroring the air temperature; but in the open waters outside warming continues slowly until well into August, depending on the weather, with the readings highest some time during the

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[21] See Copeland (1912); Mavor, Craigie, and Detweiler (1916); Craigie (1916 and 1916a); Craigie and Chase (1918); Vachon (1918); and Mavor (1923).

last half of the month. On the whole, the surface temperature of the gulf may be described as more nearly stationary from July 25 to the end of August than over any equal interval during the spring, on the one hand, or during the autumn, on the other.

The surface chart for late summer (fig. 46) represents the average state during the last week of August. Deviations in one direction or the other from the precise values there given are to be expected, however, according as the year is warm or cold, the season forward or tardy (p. 626).

The surface temperature within the gulf rises highest over the western and southwestern parts of the deep basin, at the mouth of Massachusetts Bay, and in Cape Cod Bay, as outlined by the isotherm for 18°. Within this area readings of 20° have been reported on three occasions, namely, twice by Doctor Kendall in the last week of August, 1897, and more recently on August 22, 1914 (station 10254). On the other hand, the lowest surface reading so far recorded for the last week of August in this warm subdivision, more than a few miles out from land, was 17.6° in the western basin on August 31, 1915 (station 10307). The data from the cruises of 1912, 1913, and 1914, compared with readings taken in August, 1922, and by Doctor Kendall in 1897, show that the temperature first reaches 18° at the mouth of Massachusetts Bay and out over the neighboring part of the basin in its offing,

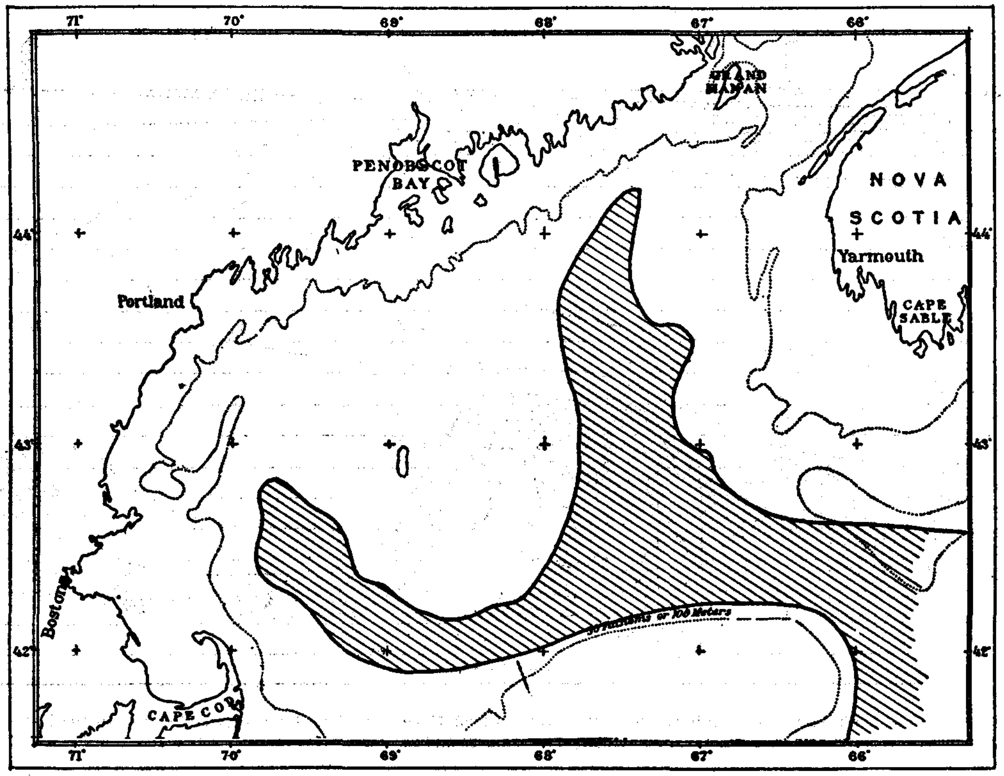

FIG. 45.—Extent of bottom water warmer than 6°, last half of June, 1915

whence the limiting isotherm (18°) spreads south as well as north, to the confines laid down on the chart, as the summer draws to its close.

We have invariably had surface readings higher than 18° in the outer half of Massachusetts Bay after the first week of August, and in Cape Cod Bay; but off the tip of Cape Cod, where tidal currents run strong, the surface is usually cooler locally, as is the general rule in such locations, with readings of 17° to 18° for the last half of August. For this same reason the coastal belt around the western and

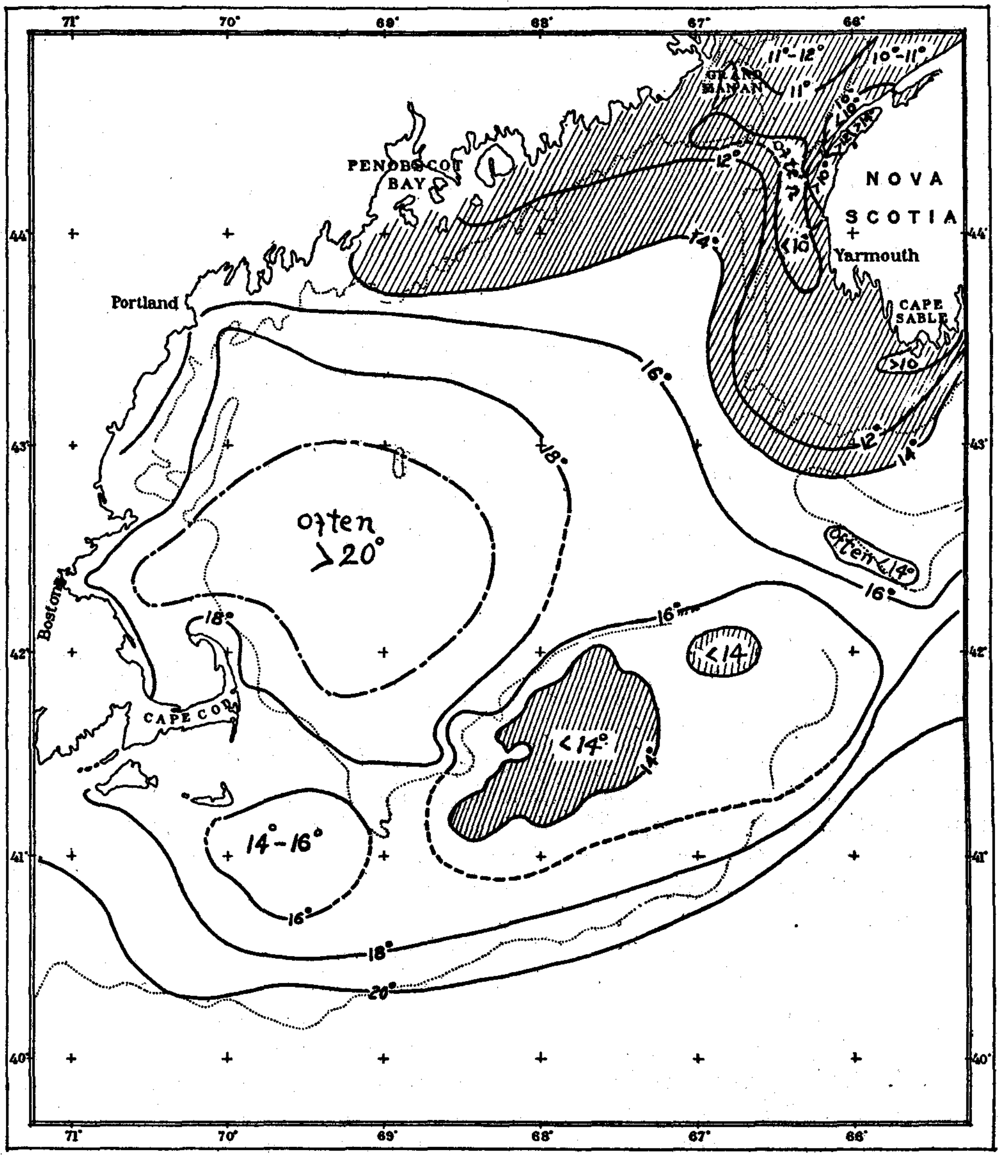

FIG. 46.—Normal surface temperature for mid-August, based on a combination of the recent station records with Rathbun's (1887) tabulation at lighthouses, the Canadian records, Dickson's (1901) data, and the daily surface readings, at Gloucester, Boothbay, and Lubec (figs. 29 to 31). (Close to Cape Sable, read < 10° for > 10°.)

northern shores of Massachusetts Bay usually remains cooler than 18° on the surface throughout the summer, though warmer than 15°; but as every bather knows, continued onshore winds sometimes drive the warm offshore water right in to the beach there, though in a surface film so thin that one's legs may be in decidedly lower temperatures while swimming. On the other hand, when westerly winds drive the surface water out to sea, cooler water wells up from below, locally lowering the surface temperature. Upwellings of this sort, combined with local stirrings by the tides, are so common an event along the northern shore of the bay that usually this is fringed by a zone, a few miles wide, where streaks of surface water warmer than 16° alternate irregularly with patches cooler than 14° to 15°, and where we have occasionally had surface readings as low as 12° in July, with 10° reported to us in August. Cold streaks of this sort are most often to be expected about the bold promontory of Nahant and along the rocky shore between Gloucester and Cape Ann.

At Thatchers Island (the tip of Cape Ann) tidal disturbances may cause considerable and irregular fluctuations in the temperature of the surface from day to day, witness readings varying from 15.6° to 17.5° during the warmest periods of the summer of 1881 (Rathbun, 1887); but a temperature of 19.4° at the cape late in July, 1882, shows that the warm surface water from offshore may touch the coast line there during calm periods or after onshore winds, as it does elsewhere.

It appears from what little precise evidence is available, and from general reports by seaside dwellers, that similar fluctuations prevail all along the coast line in August, from Cape Ann northward about to Cape Porpoise; but the surface of the coastal belt averages 1° to 2° colder in this sector than in Massachusetts Bay—usually below 16°.

It is unfortunate that daily records are not available for any station along this stretch of coast line or for the Isles of Shoals, which occupy a commanding position off the mouth of the Merrimac River. Most of our August passages, also, to and fro, have followed courses outside the 100-meter contour. Rathbun's (1887) record of maxima of 15.6° to 16.7° at Boon Island for the summers of 1881 to 1885, with our own stations between Cape Elizabeth and Cape Ann, suggest 15° to 16° as the usual maximum for the coastal sector between the Isles of Shoals and Cape Elizabeth, out to the 100-meter contour, with temperatures 1° to 3° higher a few miles farther out at sea.

The rise in surface temperature experienced as one runs offshore from Cape Elizabeth is illustrated by the following readings taken by W. C. Schroeder on the *Halcyon* on a trip to Platts Bank, July 20, 1915: 8 miles out from Cape Elizabeth, 16.1°; 17½ miles out, 19.44°; 20 miles out, 19.44°; on Platts Bank, 30 miles out, 18.9°. This agrees closely with the gradation indicated for this region on the charts (figs. 46 and 47); also with the state of the surface on August 7, 1912, when the temperature rose, progressively, from 15.6°, at a point 8 miles off the cape, to 17.8° on Platts Bank (Bigelow, 1914, p. 46).

It has long been common knowledge that the coastal waters along eastern Maine and in the Bay of Fundy are cold in summer, with a maximum difference of almost 10° C. (18° F.) between the surface there and in the offing of Cape Ann. This cold area, outlined by the isotherm for 12° on the chart (fig. 46), also includes the whole eastern side of the gulf, off western Nova Scotia, out to the 100-meter contour, in an undulating outline more easily represented graphically than verbally.

The transition from warm to cool is often very noticeable as one runs from the offing of Cape Elizabeth, across the mouth of Casco Bay, to the neighborhood of Boothbay Harbor. On August 13, 1925, for example, the *Halcyon* had surface readings of 16° at the mouth of the bay but only 12.8° close to Seguin Island. Next the shore surface temperatures ranging from 13° to 15.3° have been recorded between Casco Bay and Penobscot Bay in August; usually cooler than 14°, but with much

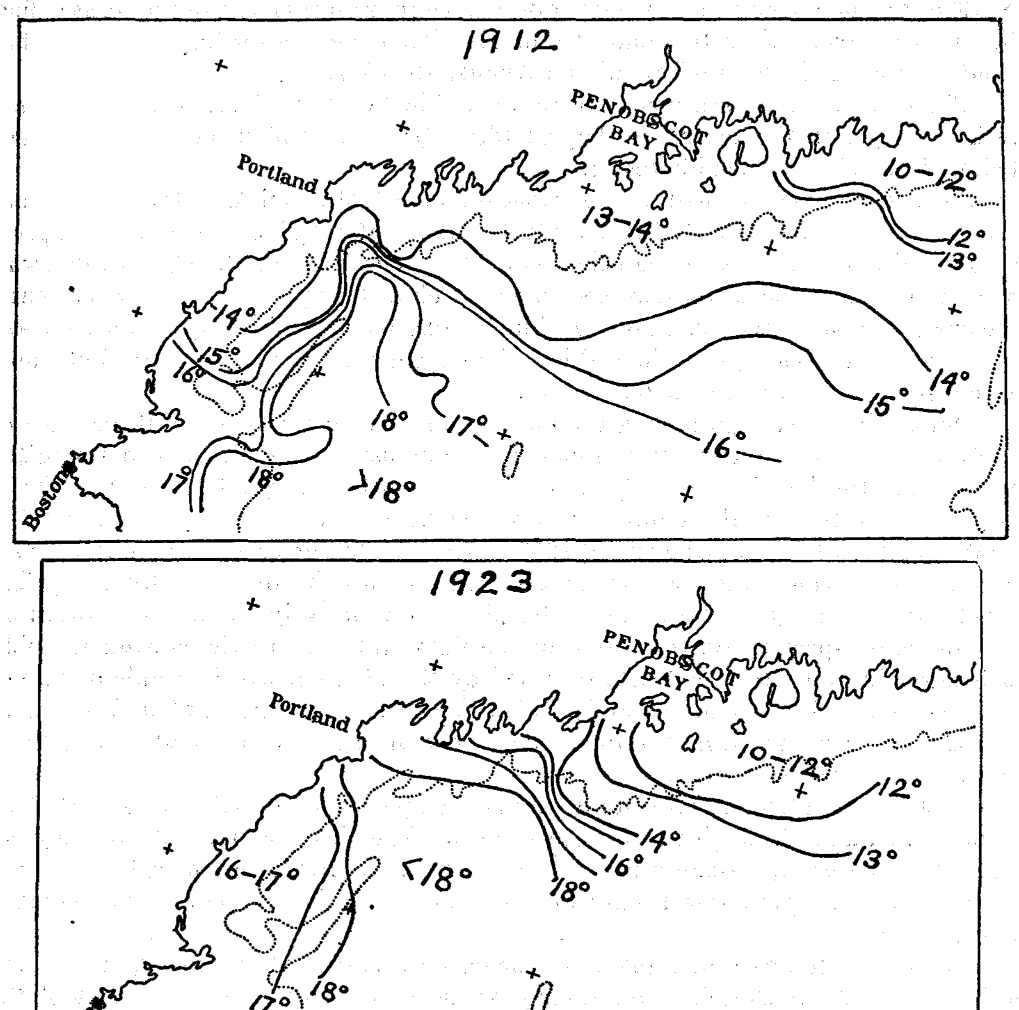

FIG. 47.—Surface temperature, July to August, 1912 (above), and July to August, 1923 (below)

local variation as the tide swirls around the islands and ledges. The maximum temperatures at Seguin Island Lighthouse for the years 1881 to 1885 (Rathbun, 1887), were, respectively, 13.3° to 13.9°, 13.3° to 13.9°, 13.9° to 14.4°, 13.9° to 14.4°, and 14.4°. This agrees with readings of 13.9° at two localities within a few miles of the island on August 22, 1912, and with 12.8° to 14° in that general neighborhood on July 18, 1925; but one need run only a few miles offshore from this part of the coast to find the surface warmer than 16°, and Doctor Kendall records a reading of 16.7° within about 8 miles of the land off Seguin on August 16, 1897.

The surface temperature rises to 16° to 18° in Boothbay Harbor during the last week of July and the month of August (fig. 30); equally high, no doubt, in other sheltered bays in this neighborhood.

Surface readings taken on a line across the mouth of Penobscot Bay ranged from 12.8° to 13.9° on August 21, 1912, while Rathbun (1887) gives maximum temperatures of 11.7° to 12.2° at the lighthouse on Matinicus Rock at the western gateway to the bay, where the water may be somewhat chilled by the swirling tidal currents. The surface in sheltered situations within Penobscot Bay may warm to a temperature several degrees higher than this before autumnal cooling sets in, but information is scant for this particular region.

Our surface readings among the outer islands along the coast of Maine, east of Penobscot Bay, and out to the 100-meter contour usually have ranged between 10° and 12° for the last half of July and for the month of August (fig. 47). After a few calm, warm days the temperature of this zone may rise locally to 13° (12.78° off Mount Desert Island, August 13, 1913, station 10099, has been our highest record there). The surface water is considerably warmer up the bays, locally, depending on the topography of the bottom as determining how actively the water is stirred by the tide, and especially on the extent of the flats laid bare to the sun on the ebb. Surface readings of 10.6° to 11.7°, recorded by the *Halcyon* within a mile or two of Great Duck and Little Duck Islands, Bakers Island, and Long Island on August 8 to 11, 1925, cover the usual midsummer range close in to the islands and among them for the Mount Desert region.

Rathbun (1887) gives maximum summer temperatures of 11.6° to 13.3° at Petit Manan light, and although the surface water off Machias was only 8.9° on July 15, 1915 (station 10301), probably it is always as warm as 10°, or warmer, there during the last half of August, and usually 11° to 12°, except where some local upwelling is taking place.

The hourly temperatures taken off the eastern coast of Maine during the last half of August, 1912, are especially interesting because they suggest a movement of the coldest surface water (colder than 13.5°) offshore (i. e., to the southwest), out past Mount Desert Rock (fig. 47). Unfortunately I can not state whether this phenomenon is regularly recurrent in summer; but the fact that the surface was slightly cooler (9.3°) near Mount Desert Rock on September 15, 1915, than close in to Mount Desert Island (9.8° to 10.8°), near Petit Manan Island a few miles eastward along the coast (10.5°), or near Swans Island to the westward (10.8°), suggests that some such distribution of surface temperature is at least not unusual for that general region.

On August 17, 1912, and again on the 19th, we had readings of 10 to 11.7° as the *Grampus* sailed lengthwise through the Grand Manan Channel; and it is probable that this is about the highest temperature attained in the tide-swept Lubec Channel, because the highest 10-day average was about 10° there during the last of August and first of September of 1920 (fig. 31). The highest mean temperature recorded at Eastport for a 10-day period for the years 1878 to 1887 was 10.7° (Moore, 1898) in the second week of September.

The surface temperature of the greater part of the open Bay of Fundy likewise ranges from 10° to 12° in August, rising above 12° only exceptionally and locally (Huntsman, 1918; Vachon, 1918). Thus, Mavor (1923) records a range from 9.44° to 12° at 19 stations on three traverses of the bay inward from Grand Manan on August 22 to 27, 1919, warmest along the New Brunswick shore, coldest (9° to 10°) near Digby Neck on the Nova Scotian side. A similar gradation is described by Dawson (1922) for the first half of August, 1907. The records given by Craigie (1916), Craigie and Chase (1918), and Vachon (1918) for the open bay, with a maximum of 12.68°, a minimum of 8.93°, in July and August, are consistent with this on the whole.

Dawson (1922, p. 92) records surface temperatures somewhat higher (14.17° to 13.33°) than this on a run from Digby to the middle of the bay on the meridian of St. John, New Brunswick (his station A), for July 22, 1907, but this may have been an unusually warm summer in the bay. At any rate, temperatures so high were briefly transitory, for the surface at his outer station had cooled to 13.6° by the next day and to 12.8° three days later (Dawson, 1922, pp. 88–92), when the surface temperature along the land from Digby Gut to Brier Island was only 8° to 9°. With a variation from 10° to 11.7° over the Fundy Deep for the three-day period, August 23 to 25, 1904, independent of the stage of the tide (Dawson, 1922, p. 95), slight changes evidently are to be expected in the bay from day to day, perhaps governed by the roughness of the sea.

Many records of temperature, surface and subsurface, have been published for the Passamaquoddy Bay region by Copeland (1912), by Craigie and Chase (1918), and by Vachon (1918), showing a considerable regional variation in the temperature to which the surface attains by the end of the summer. Copeland found the surface warmest (13.9° to 15.6°) in the northern part of the bay, coldest (10.4° to 11°) near Deer Island and in Letite Passage, with the central and western parts of the bay ranging from 11.1° to 15°. Vachon (1918, station 4), likewise records the surface of the center of the bay as warming from 11.4° on July 20 to 15.9° on July 27 in 1916, cooling to 11° on August 3 and 17, but warming again to 12.48° on the 25th and to 14.91° on the last day of the month. In the mouth of the St. Croix River, however, the water is kept so thoroughly stirred by the strong tides that Vachon's highest reading was 13.4°, the lowest 10.95°, for the period July 17 to August 31, coolest after northwest winds. Low surface temperatures also rule in Friar Roads between Campobello Island and Eastport, where Vachon reports 8.7° to 10.3° between August 2 and September 17, with 9.5° to 12.62° in the western passage between Deer Island and the coast of Maine, and with about this same range of temperature at a station near St. Andrews.

Vachon's and Copeland's records, combined, show that the temperature of the surface of the northwestern part of Passamaquoddy Bay may be expected to reach 15° for a brief period in August in warm summers, though perhaps not every year. At the other extreme, the surface water in the channels between the islands of western New Brunswick, where tidal stirring is more thorough, is seldom warmer than 11° to 11.5°. Considerable fluctuations are also recorded within brief periods in the central part of the bay, where the surface temperature is intermediate between these two extremes, and in the mouth of the St. Croix River, connected with the direction of the wind and with the stage of the tide.

It is interesting to find that no part of the surface of the Bay of Fundy,[22] with its much stronger tides, is as warm as the greater part of Massachusetts Bay, though the maximum readings for these two areas differ by only about 3° (15° for Passamaquoddy and about 18° to 19° for Massachusetts Bay).

Craigie and Chase (1918) found the surface about as cold (9° to 11°) in the outer part of the Annapolis basin on July 23 to 24, 1915, as it is along the Nova Scotian side of the Bay of Fundy outside, but progressively warmer, passing inward, to 15.33° near the head. According to Huntsman (1924), Minas Basin, at the head of the Bay of Fundy, also warms faster than the latter in summer, but the definite values have not yet been published for it.

Dawson's (1922) very considerable list of surface temperatures for 1904 and 1907, with our yearly stations off Lurcher Shoal, on German Bank, and near Cape Sable, unite to show that a cool surface is characteristic of the whole coastal zone along western Nova Scotia out about to the 100-meter contour, usually with the readings falling between 9° and 12°, as outlined by the isotherm for 12° on the chart (fig. 46). More specifically, our own surface records for the Lurcher Shoal and German Bank stations have been as follows:

Locality and date	Station	Surface temperature
Near 100-meter contour, off Lurcher Shoal:		°C.
Aug. 15, 1912	10031	13.33
Aug. 12, 1913	10096	12.22
Aug. 12, 1914	10245	14.44
Sept. 7, 1915	10315	12.20
German Bank, outer part;		
Aug. 14, 1912	10029	10.44
Do	10030	11.11
Aug. 12, 1913	10095	8.89
Aug. 12, 1914	10244	10.00
Sept. 2, 1915	10311	9.40

The constant difference between these two localities shows that surface temperatures lower than 12° do not reach offshore beyond the 100-meter contour in the offing of Lurcher Shoal, but on August 12, 1913 (station 10094), we found the surface as cold (8.89°) 12 miles out from the edge of German Bank as it was over the latter (station 10095).

As Dawson (1922, p. 99) has remarked, "as a rule, the temperature nearer shore becomes higher when the weather remains quiet," his data showing that the

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[22] For further details regarding the Bay of Fundy the reader is referred to the extensive tables given by Copeland (1912), Craigie and Chase (1918), and Vachon (1918).

water close in to the western coast of Nova Scotia warms to 10° to 12° by August from St. Marys Bay to Yarmouth. Yarmouth Harbor he found only slightly warmer (12° to 12.5°) than the open waters at its mouth, and it had about this same temperature on September 8, 1916,[23] but the surface of St. Marys Bay rises to a considerably higher temperature. The maximum for this bay can not be stated, data for the inner part of the bay for August being lacking. Craigie and Chase (1918), however, found its surface progressively warmer, passing inward, from 9° to 10° at the mouth to about 11° abreast of Petite Passage, 13° to 13.5° off Weymouth, and to 14.8° at the head during the second week of July in 1915; and as Vachon (1918) again had readings of 11.08° abreast of Petite Passage and 12.92° off Weymouth on September 4 to 5, 1916, it is not likely that August sees the surface temperature rise much above 15° anywhere in St. Marys Bay.

A coastal belt skirting Cape Sable, 12 to 15 miles wide, like the vicinity of Lurcher Shoal, is characterized by surface temperatures lower than 10° throughout July. This, no doubt, results from thorough stirring by the tides, which proverbially run strong around the cape, causing a mixture in varying amount with the icy water that persists until midsummer in the deeper strata next the coast, a few miles to the eastward (p. 681).

Near the cape Dawson (1922, p. 85, station Q) had surface readings of 5.3° to 7.5° (usually from 0.5° to 1° higher at high water than at low water) during the first half of July, 1907. By the last week of that month he found that the mean surface temperature 12 miles out from the cape had risen to about 9° at high tide and to about 8.4° at low, with a slightly greater difference between high and low tide temperatures (average about 9° and 7.2°) closer in to the land, and with a maximum of 11.95° at the high-water slack and a minimum of only 5° at low-water slack on the 20th. Our own more recent record of 10.28° near by on July 25, 1914 (station 10230), falls well within these extremes.

These temperatures suggest that the flood current, flowing westward past the cape, draws warmer surface water toward the land from offshore, but that the ebb, flowing to the eastward, carries out water that has been thoroughly mixed by the currents swirling around the cape.

Surface readings of 10° to 12° on several lines along the coast sector between Yarmouth, Nova Scotia, and the cape, for the middle of July (Dawson, 1922), show that this narrow cold pool off Cape Sable becomes entirely isolated from the low temperatures about Lurcher Shoal before the last of that month by the development of a warmer surface over the intervening area, but is continuous with still lower temperatures to the eastward along the outer coast of Nova Scotia until August, witness a surface reading of 6.62° at low water a few miles off Shelburne on July 27 in 1914 (station 10231), no doubt reflecting some updraft of the icy water from below with the outflowing tide. In 1915, however, the Canadian Fisheries Expedition found no surface water colder than 9.7° off this part of the coast on July 21 (Bjerkan, 1919). On September 6 of that year (station 10313) the surface was 15° 10 miles off Cape Roseway, 13.3° 10 miles south of Cape Sable on September 2 (station 10312), and 13.6° near by on August 11, 1914 (station 10243). Apparently, then, if the cold surface persists as late as August off the Cape, it becomes reduced to an isolated pool

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[23] Varying from 11.3° to 12.7° during that day (Vachon, 1918).

not more than half a dozen miles wide by the end of the summer, persisting only as a reflection of purely local activity of tidal stirring.

Our Gulf of Maine cruises have not crossed the southeastern part of the area in August; hence the isotherms for this region (fig. 46) are only tentative for that month, combined from the July cruise of the *Grampus* in 1914, the Canadian Fisheries Expedition stations off southern Nova Scotia for July, 1915, temperatures taken by the *Albatross* in August, 1883, and July, 1885 (Townsend, 1901), and from scattering records from other sources. These combine to show a rather abrupt transition in surface temperature in the region of the Northern Channel between the cool area along western Nova Scotia (12°) and somewhat higher readings (14° to 16°) on Browns Bank, but make it unlikely that the surface normally warms above 16° over the latter at any season. It is probable, too, that much local variation in temperature exists on Browns Bank, with cool and warm streaks caused by tidal mixings, especially along its southwestern edge fronting the Eastern Channel, where the *Albatross* had surface readings of 12.78 to 13.3° at four stations on August 31, 1883.

The surface temperature in the center of the Eastern Channel was 15.1° on July 24, 1914 (station 10227), but readings of 12.8°, 16.1°, 14.2°, and 13.3° at four successive stations on a line crossing the deep water from Georges Bank to Browns Bank on August 31, 1883, suggest that while the central core of the channel is usually fractionally warmer than 16° by the end of the summer, vertical stirrings or upwellings are sufficiently active along the edges of the two banks to maintain narrow lanes there colder than 16° on the surface.

It is probable that the surface is from 1 to 3 degrees cooler over the eastern, northern, and central parts of Georges Bank, as a whole, than in the basin of the gulf to the north throughout the summer, and certainly it is considerably cooler than the oceanic waters outside the edge of the continent to the south, just as it is in June (fig. 39). Thus, Dr. W. C. Kendall had surface readings of 12.8° to 15.3° (averaging about 14.5°) at 55 stations along the northwestern edge of the bank on August 21 to 25, 1897, and the isotherm for 16° for this region is located on the chart (fig. 46) from these observations.

This part of the bank offers an excellent illustration of the chilling of the surface that follows when cooler water from below is brought up over and around shoals by the tides, with the surface averaging 1° to 3° cooler over the shoal ground than elsewhere on the bank and (generally) coldest (13° to 14°) over the shoalest part, where the water is less than 50 meters deep. Even small isolated shoal spots may cause cool pools at the surface in this region, and the effect of projecting submarine promontories or ridges may be made evident for some miles by lowered surface temperature. Where the water is not only shoal, but the topography of the bottom is broken and tidal currents run strong, considerable variations in surface temperature also are to be expected from ebb to flood, as Dawson found to be the case near Cape Sable (p. 593). Doctor Kendall records several such alterations on Georges Bank, notably a drop of about 1.5° at a station on its northern edge during a period of a few hours on August 21. A few yards' sailing may also be enough to bring the vessel from a cool streak into a warm one, or vice versa, the explanation for which is apparent enough on calm days when the lines of contact between different runs of tide are often made visible by miniature rips, oily slicks, or by the accumulation of floating débris of one sort or another. In all this, Georges Bank, in the south of the gulf, agrees with the coastal belt generally in the northeast, as it does in being colder at the surface than is the intervening basin where "the water moves to and fro in an unbroken sheet, clear of obstruction," as Dawson (1905, p. 15) expresses it.

Doctor Kendall's temperatures, added to readings taken by the *Grampus* in July, 1908 (Bigelow, 1909), and from the *Halcyon* in the summer of 1923, show that the surface is correspondingly cool (12° to 16°) in August over the shallow broken bottom south of Nantucket, with similar fluctuations within short distances and at different stages of the tide, due to the same disturbing influence of tidal mixings. Thus, the *Halcyon* had surface readings varying from 11.6° to 15° in August, 1923, as she fished at various locations within a mile or two of Round Shoal bouy; 13.3° to 16.4° over Rose and Crown Shoal; 15.5° over the slightly deeper channel between Round Shoal and Rose and Crown Shoal; and 13.8° to 15.5° on the Great Rip fishing ground 12 miles southeast of the island of Nantucket. Unfortunately, it is not yet known whether this cold area is separated from the equally low surface temperatures of Georges Bank by a band of warm surface water along the so-called "south channel," as seems probable, or whether the cool surface forms an unbroken band, west to east, from the one shoal ground to the other.

In 1913 the surface to the seaward of the 50-meter contour off Nantucket had warmed to upward of 19° by the last week in August (Bigelow, 1915, p. 350, fig. 2, stations 10107 to 10112). This was true also of the whole breadth of the shelf abreast of Marthas Vineyard on the 26th of the month in 1914, except close in to the land (station 10263), where a surface reading of only 17.9° probably reflected some tidal disturbance or other. With this same exception, Doctor Kendall likewise had 18° to 19° at every station off Marthas Vineyard early in September, 1897, paralleling Libbey's (1891) record of surface warmer than 19° over this part of the continental shelf during August, 1889.

These data locate the isotherm for 18° as following the southern and western edges of Nantucket Shoals around into the submarine bight west of the latter, but with cool pools next the southern shores of Marthas Vineyard, as just noted.

It is probable that the surface temperature rises higher than 20° over the outer part of the continental shelf off southern New England every August, and Libbey's (1891) extensive data show that in some years temperatures slightly higher than 20° are to be expected within a few miles of Marthas Vineyard. But his records also show that a considerable variation in surface temperature is to be expected within short periods of time over the inner half of the shelf, where a sudden cooling of the surface would be the natural accompaniment of any unusual stirring of the water or of the upwellings that so often follow offshore winds.

There is also considerable variation in the surface temperature off Marthas Vineyard from year to year. In 1914, for example, the isotherm for 20° included only the outer half of the continental shelf on August 21 at longitude 71° (fig. 46).

In spite of these fluctuations, it is safe to say that the surface is invariably warmer than 20° along the edge of the continent in the offing of Marthas Vineyard and Nantucket Island by the end of August. To find the surface warming to upward of 22° to 23° it is only necessary to sail seaward a few miles farther.

Passing eastward from the longitude of Nantucket, we find a more sudden transition from the comparatively cool water (18°) over the southwestern part of Georges Bank to the high temperature of the oceanic water outside the 200 meter contour, accompanied, however, by such irregularities as might be expected along the zone of contact of waters differing in salinity as well as in temperature. At times the north-south gradation in surface temperature along this sector of the edge of the continent is also interrupted by a cooler band. On July 20 to 21, 1914 (stations 10216 to 10218),[24] this was indicated by surface readings of 18.6°, 17.3°, and 20.48° at three successive stations from north to south on a line crossing the southern slope of the bank.

Such data as are available point to an abrupt increase in the breadth of the cool wedge eastward from Georges Bank between the edge of the continent and the warm oceanic temperatures of >20°, to the seaward of the latter. Thus the surface was only about 17° at our outermost station off Shelburne on July 28, 1914 (station 10233), while the Canadian Fisheries Expedition crossed a band of 17° to 19.7° water some 70 miles wide outside the 200-meter contour in the offing of Cape Sable on July 22, 1915 (Bjerkan, 1919; *Acadia* stations 41 to 44). Unfortunately no temperatures have been taken off the slopes of Georges or Browns Banks during the last half of August of late years, but even if the isotherm for 18° should encroach a few miles farther inward by the end of the month than is represented on the chart (fig. 46), there is no reason to suppose that the surface temperature rises higher than 20° inside the 100-meter contour on the banks anywhere east of Nantucket Shoals at any season, except possibly for brief periods following persistent southerly winds.

TEMPERATURE GRADIENT IN THE UPPER 100 METERS

A differentiation in the vertical distribution of temperature between the western and eastern sides of the gulf begins to develop in June, widening with the advance of summer, until the extremes, as represented by the western basin on the one hand and by the Bay of Fundy and coastal banks off western Nova Scotia on the other, yield graphs differing widely in the upper 100 meters by August.

The most striking feature of the western type, as exemplified by the basin off Cape Ann (fig. 48) and by the bowl at the mouth of Massachusetts Bay off Gloucester (fig. 4), is that the water cools very rapidly from the surface down to a depth of 40 to 50 meters, succeeded by only a slight fall in temperature down to the 100-meter level. Whether increasing depth is accompanied by a further slight cooling or by a slight warming depends on the locality, the topography of the bottom, and to some extent on yearly fluctuations, as discussed later (p. 602). In August we have found the 40-meter level averaging from 10° to 14.5° cooler than the surface in the western side of the basin and 9° to 13° cooler at the mouth of Massachusetts Bay (figs. 4 and 5), illustrating the remarkably sudden change that any animal would experience there, from warm water to cold, by sinking down for a few meters only. Observations taken farther up the bay on August 22 to 24, 1922 (stations 10630 to 10645), showed a similar vertical chilling down to 50 meters or so, except that the

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[24] This cool band is more clearly marked, by temperature, at deeper levels, as described on page 608.

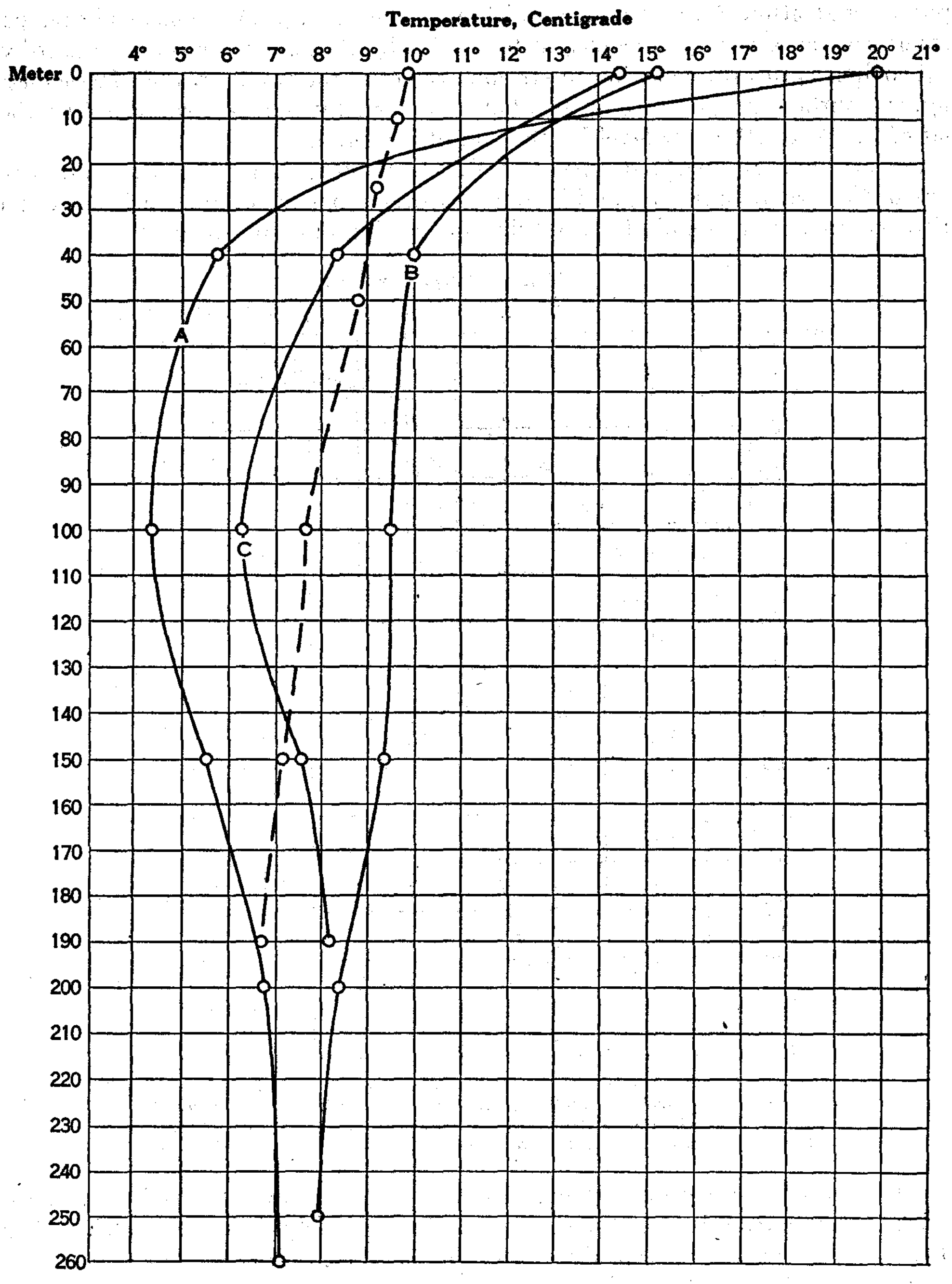

FIG. 48.—Vertical distribution of temperature at representative localities in the basin of the gulf. A, western arm of basin, off Cape Ann, August 22, 1914 (station 10254); B, southeastern part of the gulf, July 23, 1914 (station 10225); C, northeastern arm of the basin, August 12, 1914 (station 10246). The broken curve (D) is for Mavor's (1923) station 24, off the western end of Grand Manan Island, August 27, 1919

uppermost stratum, 5 to 10 meters thick, was then nearly homogeneous in temperature at several of the stations closest to the land. Although the precise rate of vertical cooling varies from station to station even over the small area of Massachusetts Bay, the surface temperature of its whole area usually warms upward of 10° above that of the 20 to 50 meter level by the end of the summer.

Serials have also yielded curves of this same general type in the west-central parts of the basin, generally, and in the northwestern part of the gulf between the latitudes of Cape Ann and of Cape Elizabeth during July and August.

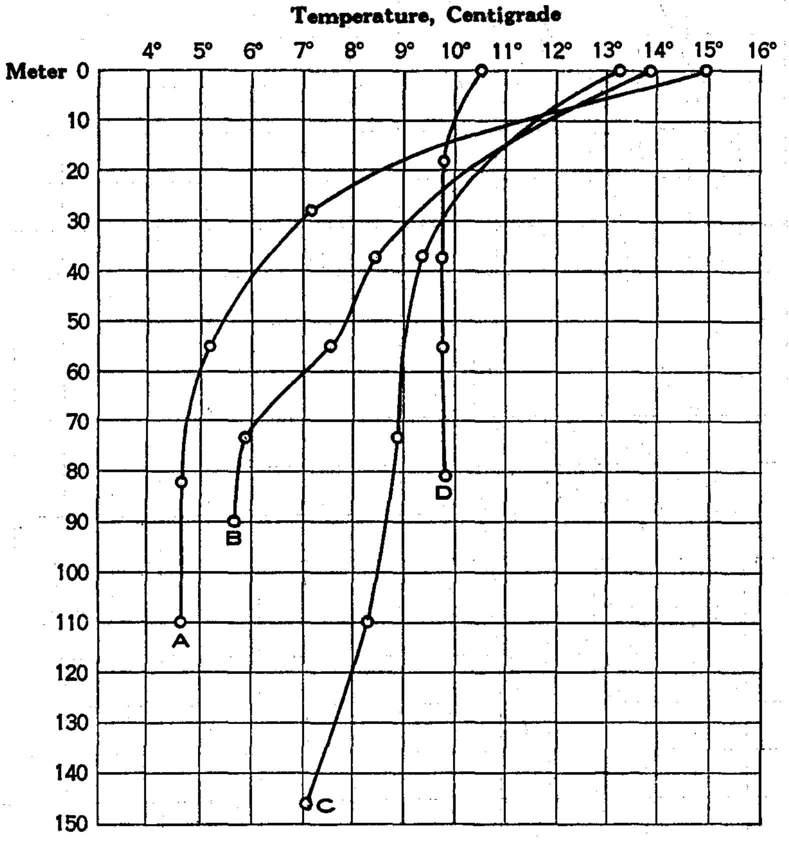

FIG. 49.—Vertical distribution of temperature at successive stations, from Cape Ann to Grand Manan, in July and August, 1912. A, near the Isles of Shoals, July 17 (station 10011); B, off Cape Elizabeth, July 29 (station 10019); C, off Penobscot Bay, August 22 (station 10039); D, off the western entrance to the Grand Manan Channel, August 19 (station 10035)

Our first summer's cruise (Bigelow, 1914, p. 51), however, proved that the difference of temperature between the surface and the underlying water (which is nearly uniform, depth for depth, from Cape Ann to Platts Bank) decreases along the coast to the eastward (fig. 49). Observations taken in the summers of 1914, 1915, and subsequently have not afforded a single exception to the rule (stated in Bigelow, 1917, p. 168) that the surface temperature is progressively lower and lower in summer, the bottom temperature (depth for depth) progressively higher and higher, around the margin of the gulf from Cape Cod to the Bay of Fundy, with the average vertical range of temperature decreasing from about 12° off Cape Ann to virtually nil in the Grand Manan Channel.

Thus, the difference of temperature between the surface and the 50-meter level (never less than about 10° at the mouth of Massachusetts Bay in summer) was only about 5° to 8° off Casco Bay (stations 10019 and 10103), 4° to 5° near Monhegan Island on August 4, 1915 (station 10303), and about 4° at the west entrance to Penobscot Bay on August 22, 1912 (station 10039). Near Mount Desert Island the vertical range for the corresponding column of water was only 2° on August 18, 1915 (station 10305), about 4° on August 13, 1912 (station 10099),[25] about 4.5° on the 5th of the month in the very cold year 1923, or an average of 3° to 4°. The water is kept even more nearly homogeneous in temperature among the islands of the Mount Desert region by strong tides, so that the surface was only 1.5° to 0.1° warmer than the bottom a couple of miles off Little Duck Island on August 8 to 11, 1925, in depths of 25 to 30 meters.

This also applies off the open coast farther east. Off Machias, for example, the surface reading was only about 1° higher than the bottom reading on August 16, 1912 (station 10033), 1.2° higher on August 13, 1913 (station 10098), 1.5° higher on August 12, 1914 (station 10247), 1.7° higher on July 15, 1915 (station 10301), and 0.33° higher on September 11 (station 10316) in 60 to 70 meters (fig. 50).

We found the surface at the two ends of the Grand Manan Channel, through which the tidal currents run with great velocity, only fractionally warmer (10° to 10.6°) than the bottom (9.6° to 9.7°) in 80 to 100 meters on August 17 and 19, 1912 (stations 10034 and 10035). Vertical stirring is thus complete at this locality.

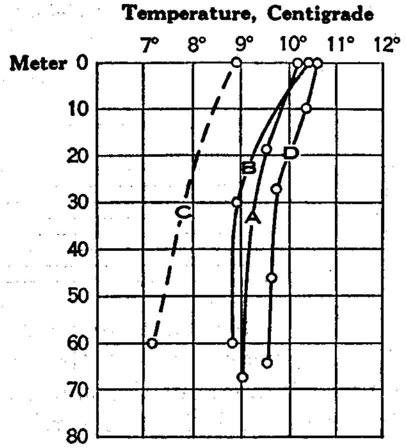

FIG. 50.—Typical summer temperatures off Machias, Me. A, August 13, 1913 (station 10098); B, August 12, 1914 (station 10247); C, July 15, 1915 (station 10301); D, August 16, 1912 (station 10033)

The temperature gradient that develops within the Bay of Fundy by the end of the summer differs regionally, depending on local variations in the tidal circulation. At the mouth, between Grand Manan and Brier Island, where tidal disturbances are proverbially strong, Mavor (1923, p. 6, Sec. IV) records a maximum difference of only 0.7° to 1.3° between the surface and 50 meters for August 27, 1919; but his Section I shows a slightly greater average range (2.2°) for the corresponding stratum at three stations halfway up the bay. This thermal difference, which develops between the Bay of Fundy and the western side of the gulf during the summer, is summarized in the following tabulation:

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[25] Forty meters was the deepest reading taken at this station.

Locality	Approximate temperature		
	Surface	50 meters	100 meters
	°C.	°C.	°C.
Bay of Fundy	10–12	7.5–9	7–8
Off Massachusetts Bay	16–20	5.5–8	4.5–6

The fact that the deep water is warmer in the Bay of Fundy, and for that matter in the northeastern part of the gulf generally, than in the southwestern, while the surface is so much colder, deserves special emphasis because of its bearing on the circulation of the two regions (p. 924).

In St. Marys Bay the relative difference between surface and bottom temperature increases from the mouth, inward, in July, as follows, if the total depth of water be taken into consideration.

Surface and bottom temperatures at successive localities from the mouth of St. Marys Bay toward its head, July, 1915. (From Craigie and Chase, 1918.)

Station	Depth, meters	Surface temperature	Bottom temperature
		°C.	°C.
21	43	9.28	8.06
15	34	10.12	8.44
11	32	11.96	9.29
8	33	12.98	9.03
6	21	13.52	10.36
4	28	13.95	11.37
2	13	13.78	11.82
1	7	14.8	13.40

The water is likewise kept comparatively homogeneous in temperature out to the 100-meter contour over the coastal banks off western Nova Scotia by active tidal stirring throughout the summer. Dawson (1905, p. 15) has already called attention to the thermal effect of vertical circulation in this region, where the topography of the bottom causes "a long trail or wake of colder water to extend from islands or shoals along the line of the current; as, for example, north and south from Lurcher Shoal." He also points out that "when the islands and shoals are numerous, the general effect of these strong currents is to chill the water in the vicinity of the coast by mixing the surface water with the colder water from below." As the result of local disturbances of this sort, the vertical range of temperature is much narrower along the 100-meter contour off Lurcher Shoal in August than at corresponding locations over the western slope of the gulf. The temperature on German Bank has proved almost perfectly homogeneous from surface to bottom in August and September, as follows:

German Bank approximate temperatures

Depth, meters	Aug. 14, 1912, station 10029	Aug. 12, 1913, station 10095	Aug. 12, 1914, station 10244	Sept. 2, 1915, station 10311
	°C.	°C.	°C.	°C.
0	10.33	8.89	10.00	9.44
20	9.83	8.67	9.85	10.30
40	9.67	8.61	9.64	10.20
60	9.61	8.56	9.65	10.10

Dawson's (1922) records for 1904 and 1907 show only a slightly greater vertical range of temperature close in to the west Nova Scotian coast, with little change during the month of August.

Temperatures for 1907. (After Dawson, 1922)

Depth	Seventeen miles southwesterly from Yarmouth		Six miles easterly from Lurcher Shoal
	July 29 to 31	Aug. 28 to 31	Sept. 2
	°*C.*	°*C.*	°*C.*
Surface	9.7-10.8	9.4-10.6	10.8
27 meters	7.5- 8	8 - 8.6	9.2
55 meters	7.2- 7.5	7.8- 8	

Tidal currents keep the water as thoroughly stirred near Cape Sable as they do on German Bank, so that Dawson (1922, station Q) found the temperature virtually uniform (about 4°) from surface to bottom 12 miles south of the cape on July 2, 1907. Observations taken by Dawson in this neighborhood later in the summer, however, in three different years, and from the *Grampus* in 1914 and 1915, show that the surface then warms rapidly enough to produce a considerable range of temperature by the end of August, except when temporarily disturbed by the tide, as just described (p. 593).

Temperatures 12 miles south of Cape Sable, °C. (From Dawson, 1922, station Q)

Depth	July 2, 1907	July 10, 1907	July 13, 1907	July 19, 1904[1]	July 20, 1904[1]	July 20, 1904[2]
Surface	4.2	6.7	7.0	9.4	12.0	5.0
27 meters	3.9	6.4	6.4	3.0	3.3	4.3
55 meters	3.9			2.8	2.8	3.9

[1] High tide. [2] Low tide.

Grampus temperatures near Cape Sable, °C.

Depth	July 25, 1914, station 10230	Aug. 11, 1914, station 10243
Surface	10.28	13.61
30 meters	3.03	7.47
50 meters	3.14	
55 meters		3.51

A wide vertical range of temperature also has been recorded across the whole breadth of the continental shelf, in the offing of Shelburne, for the last week of July, both in 1914 and in 1915, with the surface averaging about 7.3° warmer than the 50-meter level for all these stations[26] (maximum difference about 11°, minimum 4.6°). This thermal contrast continues to develop during the summer near the land off Shelburne, where the surface (15°) was nearly 13° warmer than the bottom (2.2°) at a depth of 70 to 80 meters on September 6, 1915 (station 10313).

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[26] *Grampus* stations 10230 to 10232; *Acadia* stations 37 to 40 (Bjerkan 1919).

TEMPERATURE GRADIENT IN DEPTHS GREATER THAN 100 METERS

The deeps of the gulf at depths greater than 100 meters have shown interesting variations, regional and annual, in the vertical distribution of temperature in summer. In the bowl off Gloucester, isolated from the bottom water of the open gulf by its barrier rim (p. 520), the temperature has either proved virtually homogeneous vertically, from the 100-meter level downward, or has been fractionally coldest on the bottom at that season. The water has also been slightly colder at the bottom than at 100 meters at all our summer stations in the deep trough north of Cape Ann, which is inclosed by the shoal ridge known as Jeffreys Ledge (fig. 6).[27]

In the open basin of the gulf, however, the bottom water may either be about the same temperature as the mid-stratum or may be decidedly warmer and much salter, depending, probably, on the amount of slope water flowing into the gulf at the time (Bigelow, 1922, p. 165), and the records suggest a tendency for the one or the other of these alternate states to persist over a period of years.

In July and August, 1912, the western, northwestern, and northeastern parts of the basin were virtually homogeneous in temperature (4.6° to 5.2°) from the 100 to 150 meter level down to the bottom in depths of 190 to 230 meters (stations 10007, 10023, 10024, 10036, and 10043); equally uniform vertically at depths greater than 75 to 100 meters in the eastern side (station 10028, 7.4°), or slightly colder on bottom there (station 10027, 6°).

During the summer of 1913, however, we found this type of vertical distribution replaced by the alternate state just described, with the water of the basin coldest at about 100 to 110 meters, warmer at greater depths, both in July and in August, as follows:

Depth, meters	Station 10058	Station 10088	Station 10090	Station 10092	Station 10093
	°C.	°C.	°C.	°C.	°C.
82				5.56	
91		5.17	6.39	5.83	5.56
110	4.78				
165	5.17				
183		6.28	6.61	6.11	
220					5.89
238				6.05	
274		6.33			

Only at the head of the eastern trough (stations 10096 and 10097) and on the northern slope of the basin off Monhegan Island (station 10102) was the bottom slightly colder than the 100-meter level in that summer (fig. 8).

The water was again coldest at about the 100-meter level at every deep station in the inner parts of the gulf in July and August of 1914, and with the vertical warming of the deep water not only much more pronounced than in 1913 but extending right down to the bottom in most cases. Only at one station (10249) for that summer was the temperature slightly lower on bottom than at 150 meters, as follows:

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[27] The 100-meter temperature at this locality has ranged from 4.4° to 5.4° in August of 1913 and 1914 (stations 10104, 10105, and 10252), with 3.6° to 4.7° at 130 meters, 4.3° at 155 meters. On Aug. 7, 1923, the 30 to 80 meter stratum (about 4°) was 2° to 3° colder

Deep temperatures (°C.) in the western, central, and northeastern parts of the basin, July and August, 1914

Depth, meters	Station 10214	Station 10246	Station 10248	Station 10249	Station 10251	Station 10254	Station 10255	Station 10256
100	4.22	6.28	7.18	5.31	4.41	4.36	3.95	4.24
145					4.93			
150	5.12	7.58	6.04	6.04		5.51	5.13	5.38
180							6.24	5.68
190	5.53	8.17	8.34					
200						6.8		
220				5.83				
260						7.09		

However, this type of gradient did not extend to the southeastern part of the basin (station 10225), where the temperature decreased, though at a decreasing rate, from the surface right down to the bottom. This was also the case in the Eastern Channel (station 10227).

In 1915 the deep stations again exhibited vertical warming with increasing depth in both sides of the basin in August and the first part of September, from the 100 to 150 meter level down to the bottom; but the depth at which the water was coldest (100 to 150 meters) was not so uniform as it had been the year before, nor was the vertical range of temperature below this stratum as wide. One station in the center of the basin (10308) showed a progressive cooling toward bottom instead of the more general rise in temperature, perhaps reflecting some disturbance of the normal circulation by the tides flowing around the slopes of Cashes Ledge.

Deep temperatures, °C., August to September, 1915

Depth, meters	Station 10304	Station 10307	Station 10308	Station 10309	Station 10310
90			6.36		
100	6.22	5.01		5.72	5.56
150	4.78	5.1		5.77	
165			5.63		
190					7.1
200	6.89	5.7			
210				5.98	
235		6.36			

Only one deep serial was taken in the basin of the gulf north of Georges Bank during the summer of 1916 (10345, July 22; southwest part of basin off Cape Cod), again proving the water coldest at the 100-meter level (3.85°) and fractionally warmer (4.06°) on the bottom in 150 meters. Thus the fact that this was an unusually cold year, from the gulf southward to Chesapeake Bay (p. 628; Bigelow, 1922), both in land climate and in the upper 100 meters of water, was not reflected in the vertical distribution of temperature in the deeps of the gulf. Again, this also applies to August, 1923, another cold summer (p. 632), when the temperature off Mount Desert Rock[28] was lowest (4.5°) at about 90 meters, warming to 4.9° at about 130 meters and to 5.4° at 165 meters.

A considerable body of evidence has thus accumulated to prove this the usual state in the inner parts of the open basin of the gulf during the late summer, just as

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[28] Lat. 43° 52′ N., long. 67° 54′ W., Aug. 6.

it is earlier in the season, with the temperature lowest between the 100 and 150 meter level, though with its precise gradient varying from summer to summer.

Temperatures fractionally higher close to bottom than in the mid depths have also been recorded at several stations in the deeper parts of the Bay of Fundy in the summers of 1915, 1916, and 1919. Craigie and Chase (1918), for example, found the water midway between Letite Passage and Grand Manan coldest (5.59°) at 55 to 110 meters and fractionally warmer (5.7°) at 137 meters and 208 meters (5.66°). Vachon (1918) again found the bottom water slightly warmer than the mid-stratum at *Prince* station 3, off the eastern end of Grand Manan, on July 24, 1916, and Mavor (1923) records a similar gradient at this same locality on September 4, 1917—from 5.94° at 125 meters to 6.15° at 150 meters and 6.06° at 175 meters. However, the water was coldest there on bottom on August 25, 1916, and again on August 26, 1919 (Vachon, 1918; Mavor, 1923), just as Craigie (1916a) recorded it for August, 1914.

TEMPERATURE GRADIENT ON THE OFFSHORE BANKS

No serial observations have been taken in the Northern Channel between the coastal bank off Cape Sable and Browns Bank in August; but a range of nearly 5.5° there on July 25, 1914 (station 10229) between the temperature at the surface (11.44°) and near bottom in 100 meters (5.96°) makes it likely that the contrast is still wider at the onset of autumn.

Our only late summer serial on Browns Bank (station 10228, July 24, 1914) showed a vertical range of about 6.2° between the surface (14.72°) and the 40-meter level (8.35°), with the temperature then rising fractionally, with increasing depth, to 8.5° near bottom in 85 meters. The surface was also about 6° warmer than the bottom at two *Albatross* stations[29] on the western and southern slopes of this bank on August 31 to September 1, 1883, in depths of 146 and 119 meters, as tabulated below:

Temperatures on the slopes of Browns Bank, °C.

Date and station	Surface	40 meters	Bottom
Aug. 31 to Sept. 1, 1883:[1]			
20065	12.8	----------	7° at 146 meters.
20066	12.2	----------	6.4° at 119 meters.
July 24, 1914:			
10228	14.72	8.35	8.5° at 85 meters.

[1] From Townsend (1901).

Values slightly lower here in 1883 than in 1914 probably reflect the difference to be expected between warm and cool summers, and not a seasonal succession, because there is every reason to expect higher temperatures here late in August than in July.

The Eastern Channel was also about 6° warmer at the surface than at 40 meters on July 24, 1914 (station 10227).

The shoaler parts of Georges Bank correspond more nearly to the waters along western Nova Scotia in the temperature gradient, with strong tidal currents, with which every fisherman is familiar, responsible for a nearly homogeneous state of the water over the parts of the bank where they are most active.

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[29] Dredging stations 20065 and 20066 (Townsend, 1901, pp. 393 and 394)

Such, for example, was the case near the northern edge of the bank on July 23, 1914 (station 10224), when surface and bottom temperatures (11.11° and 10.78°) differed by less than 0.5° in 55 meters depth. This same state prevailed at a station on the western end of the bank (10059) on July 9, 1913 (surface 13.3°; bottom 12.6°), and again on July 23, 1916.[30] In August, 1896, Doctor Kendall found a maximum difference of only about 1° between surface and 18-meter readings at many localities along its northern and northwestern sides.

On the parts of the bank where the water is more than 50 to 60 meters deep, and where tidal currents do not run so strong, the surface warms more rapidly during the progress of summer, the bottom less so; witness readings of 14.8° to 17.8° at the surface and 6° to 9° on bottom in 60 to 70 meters on the northern and eastern parts in August, 1926 (stations 20203 to 20208). The temperature gradient likewise differs widely from place to place in the Nantucket Shoals region in the late summer, depending on the topography of the bottom, with the water most nearly homogeneous over the shoal banks and ridges. Thus, the temperature of the entire column of water was 10° to 10.5° in 30 meters at a station 12 miles ESE. from Round Shoal buoy on July 15, 1924 (station 10655); and in August, 1925, when a greater number of serials was taken, the surface was invariably less than 1° warmer than the bottom on Rose and Crown Shoal, Round Shoal, and Great Rip in depths ranging from 20 to 30 meters, the actual temperatures ranging from 11.5° to 15° from station to station (p. 595).

The surface temperature rises high above that of the bottom water by the end of the summer over the smoother bottom to the south of the shoals, a regional contrast illustrated by two *Grampus* stations for July 25 and 26, 1916. One of these, located on the southern edge of the shoals (station 10355), was only about 1° warmer (11.95°) at the surface than at the bottom (10.97° in 30 meters). The other, in deeper water 23 miles to the southeast (station 10354), was 5° warmer at the surface (13.6°) than at the 30-meter level, and 7.6° warmer than on bottom at a depth of 70 meters. Readings of 16.1° at the surface, 14.1° at 18 meters, and 10.2° at 46 meters, near by, show about this same vertical range on July 9, 1913 (station 10060). A steep temperature gradient also develops to the west of the shoals by the end of August, illustrated by *Grampus* stations 10258, 10259, and 10263 (p. 987), and by the many serials taken off southern New England by Libbey (1891) in 1889.

TEMPERATURE GRADIENT ALONG THE CONTINENTAL EDGE

Sudden fluctuations in temperature are to be expected along the edge of the continent where the conflict between warm oceanic and cool coastal waters is constant. The station data do, in fact, show wide variations in the upper 100 meters along this zone (fig. 51). The one extreme, which may fairly be described as subtropical, is exemplified by stations 10218, southwest of Georges Bank, July 21, 1919, and station 10261, in the offing of Marthas Vineyard, August 26, 1914. These chill, with increasing depth, from a very warm (20° to 24°) surface stratum to 7° to 9° at 400 meters and to about 5.25° to 6° at 500 meters. These contrast with stations showing a well-marked cold stratum at 40 to 80 meters, as south of Cape

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[30] Station 10347, surface 11.39°, bottom 9.61° in 60 meters; station 10348, surface 11.67°, bottom 11.26° in 51 meters.

Sable on June 24, 1915 (station 10295), south of Georges Bank on July 24, 1916 (station 10253), and at several of Libbey's (1891) August stations in the offing of Marthas Vineyard. Various intermediate gradients are to be expected, also. Serials taken southeast of Georges Bank on July 24, 1914 (station 10220), and off Shelburne a few days later (station 10233), are cases in point. So, too, are many of Libbey's stations and the *Acadia* stations in the offing of Cape Sable for July, 1915 (Bjerkan, 1919).

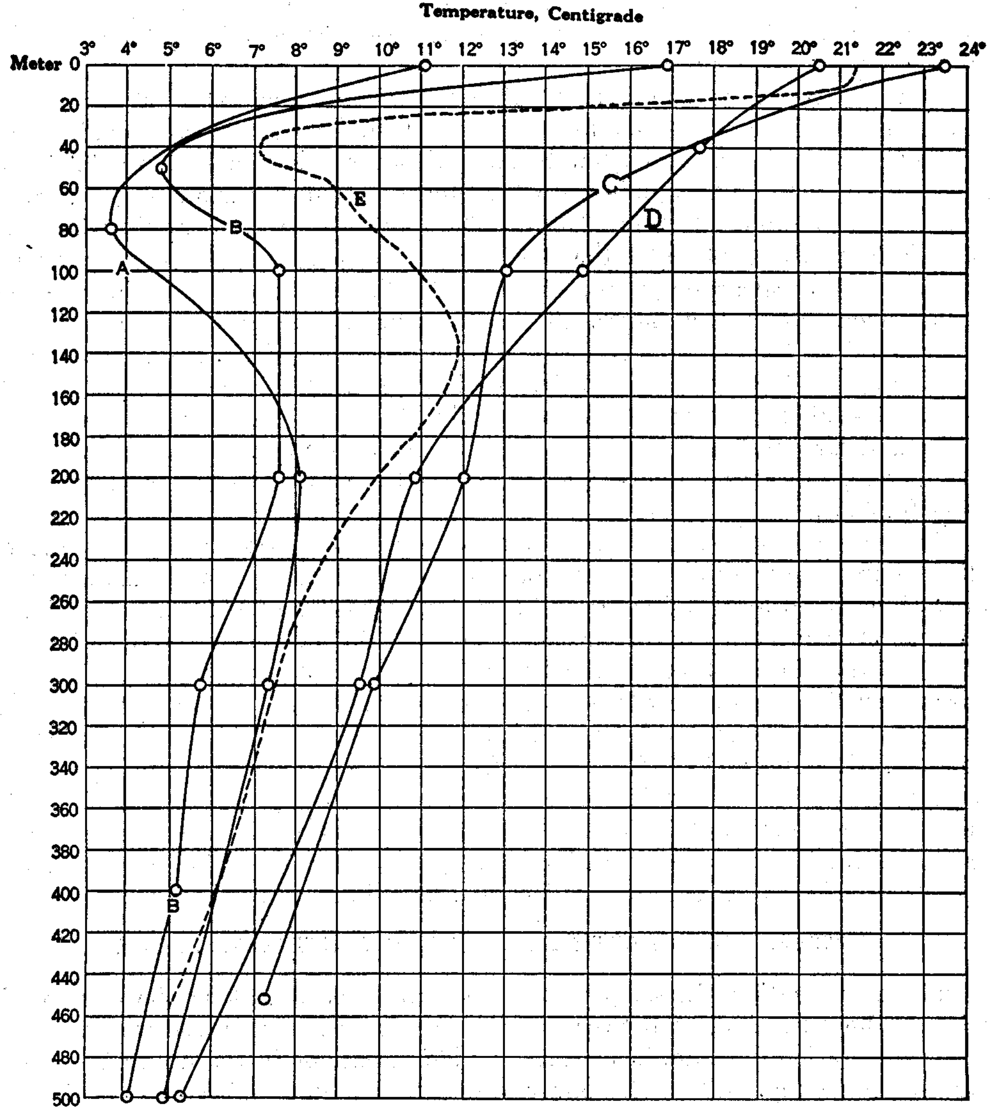

FIG. 51.—Vertical distribution of temperature on the continental slope in summer. A, abreast of Shelburne, Nova Scotia, June 24, 1915 (station 10295); B, on the southwestern slope of Georges Bank, July 24, 1916 (station 10352); C, on the southwest slope of Georges Bank, July 21, 1914 (station 10218); D, south of Marthas Vineyard, August 26, 1914 (station 10261). The dotted curve (E) is for Libbey's (1891) station 9, line G, south of Marthas Vineyard, August 17, 1889

TEMPERATURE AT 40 METERS

The regional differences that developed in the vertical distribution of temperature between various parts of the Gulf of Maine, as the summer advances, tend to make the temperature (as plotted in the horizontal projection) more nearly uniform in the mid depths than it is at the surface. Thus, all the 40-meter readings for the month of August of the years 1912 to 1915 (figs. 52 to 54), and 1922 (omitting for the moment the cold summers of 1916 and 1923), have fallen within a range of 6°, from a maximum of 11.5° off Lurcher Shoal (station 10031, 1912) to a minimum of 5.5° off Cape Sable (station 10243, 1914). Only 6 August readings at 40 meters, out of a total of 64, have been as warm as 10° to 11°; only 3 cooler than 6°, and the great majority have fallen between 7° and 9.5°, irrespective of precise geographic location. Consequently, this may be taken as the normal temperature to which the 40-meter stratum of the gulf as a whole warms by the end of the summer.

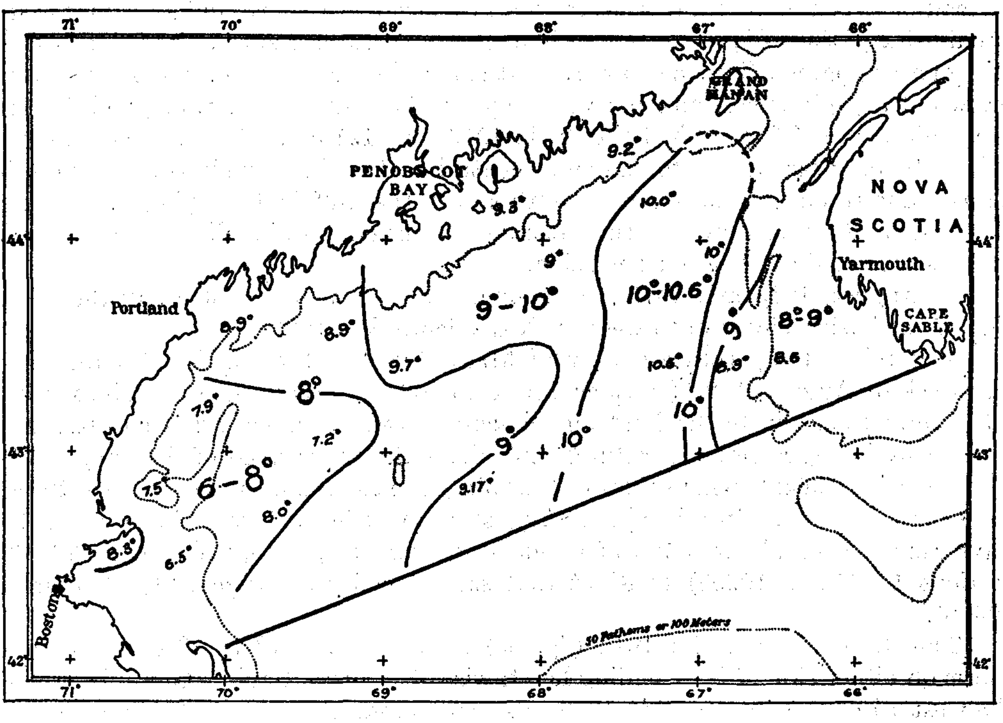

FIG. 52.—Temperature at a depth of 40 meters, August 5 to 20, 1913

With so narrow a range, and with the water continuing to warm until well into the autumn, a difference in date of a few days one way or the other will be accompanied by a greater difference in temperature, at this level, than any regional difference that might be disclosed by a simultaneous survey of the whole western and northern part of the gulf.

Differences between cold and warm years, illustrated by a temperature of about 8° on August 9, 1913 (station 10088), but only 5.75° at the same locality in 1914 on the 22d of that month (station 10254), likewise outweigh the regional differences for this station. Consequently, I have not found it possible to chart the normal isotherms for values between 6° and 10° for the 40-meter level for August, except for the very obvious fact that the whole Gulf of Maine is then 4° to 5° warmer at this level than is the water along the outer coast of Nova Scotia, where the 40-meter temperature was about 1.9° to 3° in July, 1914, warming to about 3.4° off Shelburne by the first week of September in 1915 (stations 10313 and 10314).

If the gulf north of Georges Bank be arbitrarily divided into two subdivisions by the meridian of Penobscot Bay (69° W. long.), the average of all the 40-meter readings to the west of it is 7.4° for August, 8.8° in the eastern subdivision (omitting the Bay of Fundy).

When the August temperatures for the several years are studied individually, instead of in combination, this separation into a cooler western and a warmer eastern subdivision of the gulf proper, but with much colder water east of Cape Sable, becomes still more apparent (figs. 52 to 54). Although the precise readings vary a degree or two at any given station from year to year, the 40-meter charts agree in locating the coldest area (6° to 8° in 1914; 9° in 1913 and 1915) in the western side of the gulf, extending eastward into the south-central part of the basin in wedgelike outline. Thus a line running from north to south across the gulf in the offing of Penobscot Bay would alternately cross warm water next the coast, fractionally cooler farther out, and warmer again in the southern side.

In August, 1913 and 1915, the 40-meter level was warmest along the eastern side of the basin; closer in to western Nova Scotia in 1914.

A detailed temperature survey of Massachusetts Bay, carried out during the last week of August, 1922 (stations 10631 to 10645), gave 40-meter values of 7° to 8.5°—lowest close in to the land off Gloucester (where upwelling is so often made evident by low surface temperature) and along the inner edge of Stellwagen Bank (5° at station 10632), where tidal overturnings are to be expected because of the contour of the bottom. In other years August readings in the bay at the 40-meter level have ranged from about 6.5° (off Gloucester, August 9, 1913, and August 22, 1914, stations 10087 and 10253) to 8° at that same locality on August 31, 1915 (station 10306).

The 40-meter chart for 1914 (fig. 53) shows a band 1° to 3° cooler than the water on either side of it extending lengthwise of Georges Bank. Our July profile of the western end of the bank, in 1916, also cut across a similar but still cooler band (p. 629; about 4° to 5°) just outside the 100-meter contour (station 10352). Although nothing in our previous experience foreshadowed summer temperatures there as low as those of that year, the presence near by of a similar cold stratum (10.8°) at about 75 meters in July, 1913 (station 10061), and temperature gradients of the same sort recorded in the offing of Marthas Vineyard by Libbey (1891), show that a cool band of this sort may be expected along the offshore edge of Georges Bank in most summers. In some years this extends as far west as the longitude of Marthas Vineyard as late as August, but in other years it is obliterated there at an earlier date by encroachments of the warm oceanic water from outside the edge of the continent, as happened in 1914 when the 40-meter level had warmed to 12.5° to 13.7° right across the shelf abreast of Marthas Vineyard by the last week of August.

Temperatures higher than 15° are always to be expected only a few miles outside the edge of the continent during July and August at 40 meters, as illustrated by our station data for 1914 (fig. 53), but there is no evidence that the 40-meter stratum ever warms to so high a temperature as this anywhere within the 200-meter contour abreast the Gulf of Maine.

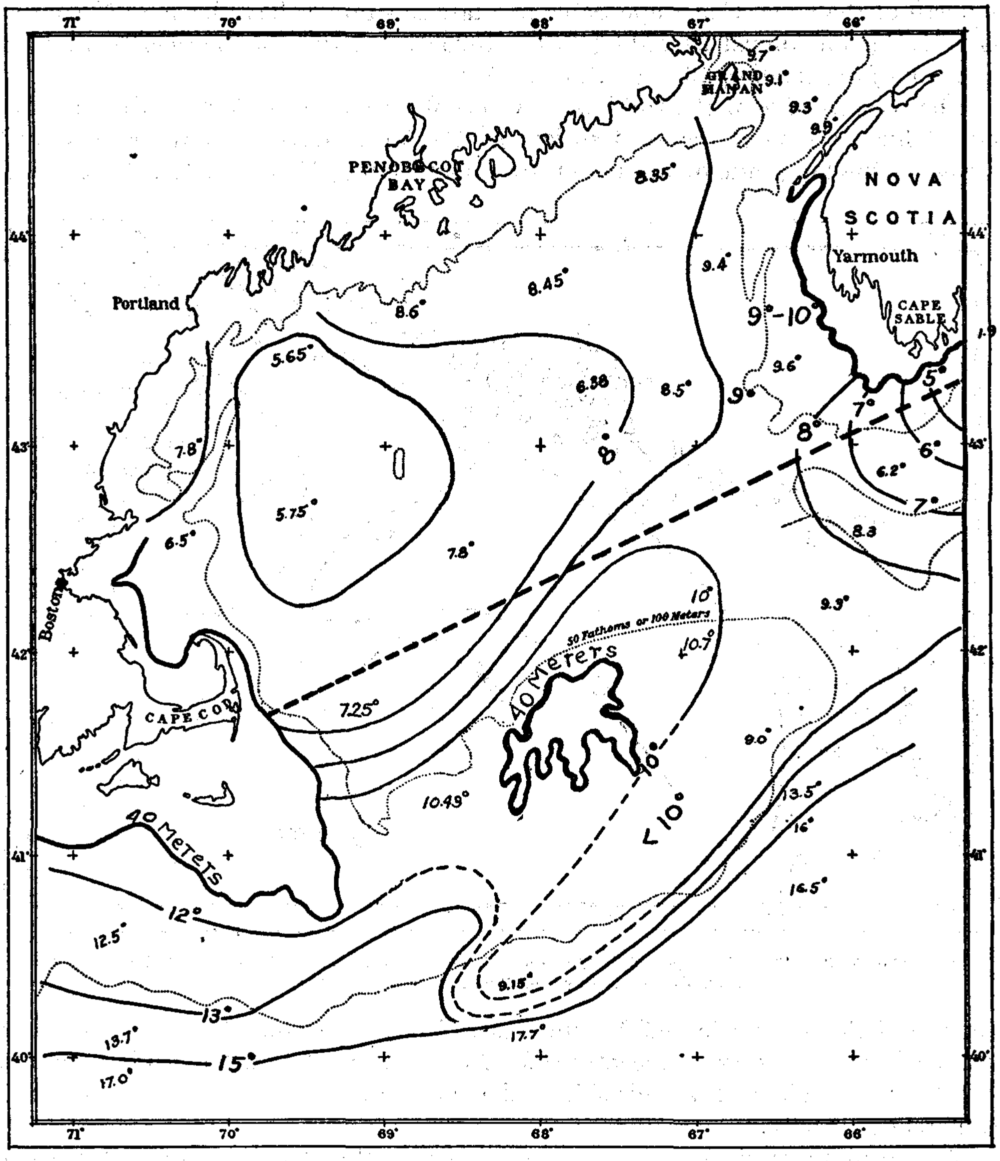

Fig. 53.—Temperature at a depth of 40 meters for July-August, 1914. North of the heavy broken line (Cape Cod to Cape Sable) the chart represents the state of the gulf from August 11 to 24; south of it, for July, combined with August. The Bay of Fundy temperatures are from Craigie (1916b)

TEMPERATURE AT 100 METERS

The 100-meter level has an especial interest as representative of the stratum usually coldest in the gulf in summer. Here the extremes of temperature so far recorded to the north of the Cape Cod-Cape Sable line late in summer have been 3.95° south of Cashes Ledge on August 23, 1914 (station 10255), and 10° near Lurcher Shoal in the first week of September, 1915 (station 10315).

The western side of the gulf has proven cooler than the eastern at the 100-meter level. Thus, 100-meter readings as low as 4.4° to 5° have been recorded only to the west of the longitude of Mount Desert Island (long. 68° 30′ W.), with the single exception of the one station off Mount Desert Rock on August 9. The fact that all but one of the 100-meter temperatures for August west of that longitude have been below 5.5°[31] is evidence that this side of the gulf is uniformly the cooler at this level, not merely so locally.

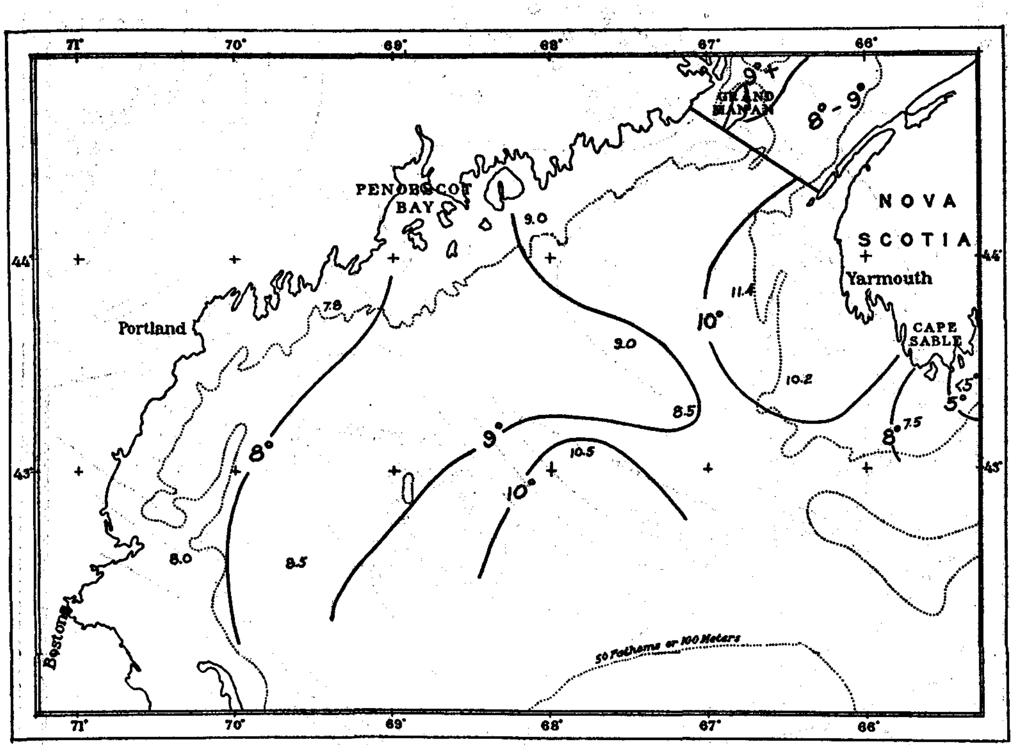

FIG. 54.—Temperature of the northern part of the gulf at a depth of 40 meters, August 31 to September 11, 1915. The Bay of Fundy temperature is for 1919, according to Mavor (1923)

The absolute values vary from year to year within narrow limits, so that the isotherm most graphically dividing the cold western area from the warm eastern area in any given summer may be 5°, 6°, or even 8°. In each August of record this critical curve, parting the gulf, has followed a characteristic S-like course (figs. 55 and 56), with the warmest water following the eastern side of the basin around to

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[31] The exception is station 10043 off Cape Cod, with a 100-meter temperature of about 6° on August 29, 1912.

the north and west, so that a line run south from Mount Desert Island would alternately cross a warm tongue and then cooler water at 100 meters, just as at 40 meters (p. 608).

This regional distribution of temperature is precisely the opposite of the surface state (fig. 46), where the gulf is warmest in the west and coolest in the northeast, a

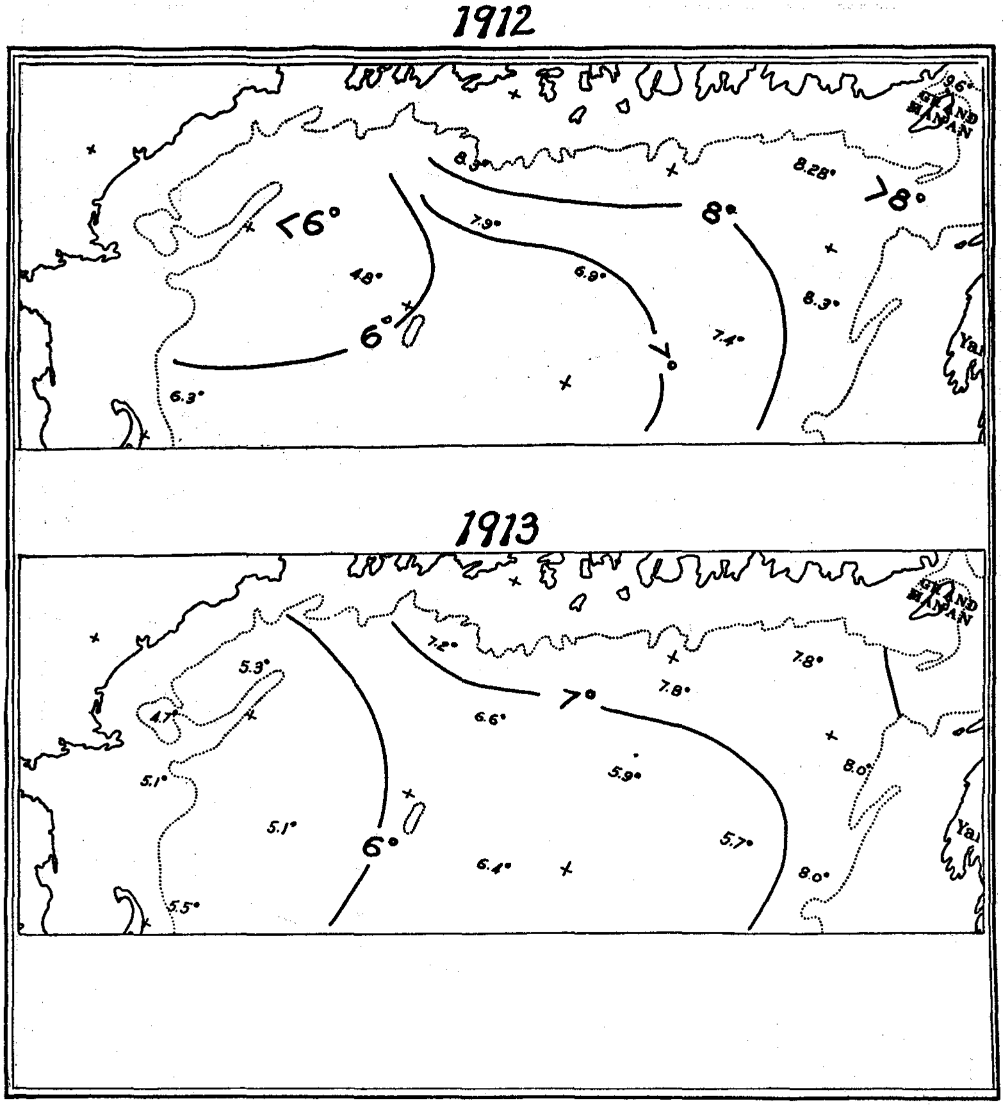

FIG. 55.—Temperature at a depth of 100 meters, August, 1912 (above), and August, 1913 (below)

difference discussed in a later chapter (p. 924). In August, 1912 and 1913, this warmest zone at 100 meters extended westward along the coast of Maine as far as longitude 69° 30′. In 1914 it hardly passed the mouth of Penobscot Bay. In all three years—1913 to 1915—the 100-meter temperature was 3° to 4° higher along the eastern slope of the basin (8° to 8.6°) than in the opposite side of the gulf.

Craigie (1916a) had temperatures of 8.15° to 9.25° at 100 meters in the Bay of Fundy on August 27 to 29, 1914, corresponding closely to about 9.6° in the Grand Manan Channel at this depth on August 17, 1912 (station 10034). In 1919, Mavor (1923) found the 100-meter level about 2° colder than this (6.9° to 8.5°) at a number of stations in the lower half of the bay at the end of August; but it is probable that the regional distribution of temperature was about the same in the two summers, with the water slightly coldest in the center of the bay abreast of the western end of Grand Manan Island.

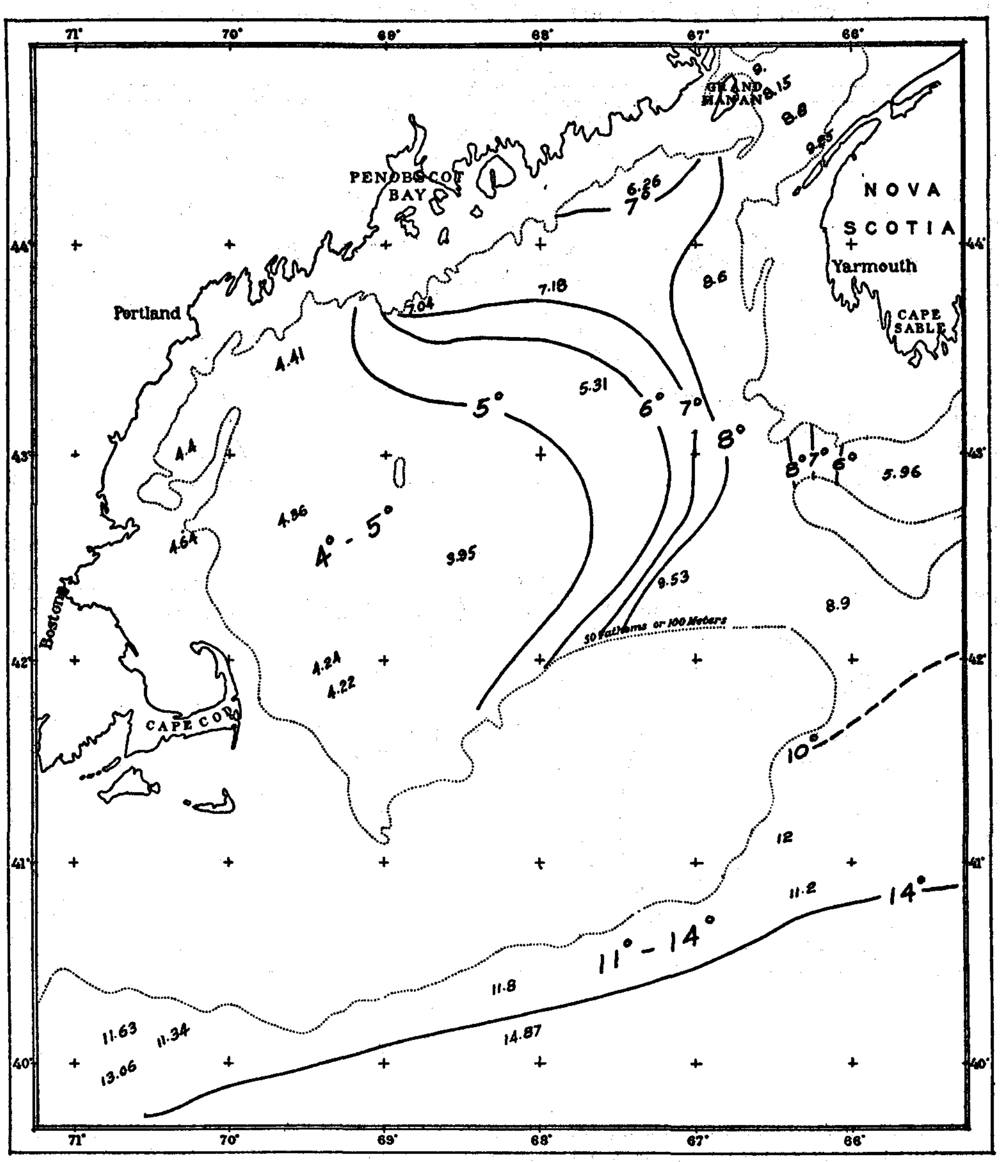

FIG. 56.—Temperature at a depth of 100 meters, July to August, 1914. North of Georges Bank the chart represents the state of the gulf during the last half of August; south of the bank the data are for July and August combined

Notwithstanding the paucity of August data for the open gulf proper south of the Cape Cod–Cape Sable line (p. 594), it is possible to estimate the 100-meter temperature of the southeastern part of the basin, of the Northern and Eastern channels, and along the oceanic slope of Georges Bank from the July stations for 1914, because the general cycle of temperature makes it practically certain that these localities would have been found slightly warmer in August. On this assumption, the 100-meter level is about 3° colder in the Northern Channel[32] than in the neighboring part of the basin of the gulf to the west, with still lower temperatures (2° to 5°) over the inner half of the continental shelf along the outer coast of Nova Scotia (Bigelow, 1917, p. 182, fig. 16). The rather abrupt east-west transition in temperature at the western end of this channel (fig. 56) also is evidence that no general movement was taking place in either direction along its trough at the time.

In the Eastern Channel, however, the 100-meter water (8° to 9°) is about as warm as it is in the eastern side of the gulf, with a gradual transition to still higher readings (11°) along the continental edge and to 14° and higher a few miles farther offshore. However, the precise distance it is necessary to run out from the edge of the continent to find water as warm as this at the 100-meter level, on any given date, depends on the circulatory interaction between the cool banks water and the much warmer and salter oceanic water of the Atlantic Basin. Probably, however, the isotherm for 14° is always closer to the edge of the banks to the west of longitude 68° than to the east of that meridian.

The low temperature (8.98°) on the southeastern face of Georges Bank at 90 meters (station 10222) deserves attention because it suggests a drift of cool water out of the gulf around the peak of the bank, salinity being too low there (34.18 per mille) to allow of upwelling up the continental slope from the mid depths offshore as a possible cause. This is corroborated by the density there, as explained below (p. 958).

The 100-meter level remains much more nearly constant in temperature throughout the summer than do the overlying waters, with readings only about 1° higher in the western side of the gulf at the first of September, 1915, than they had been during the last week of the preceding June.

In the eastern side of the gulf, where solar heat is more rapidly dispersed downward by more active vertical circulation, the 100-meter level may be expected to warm by 2° to 3° from June to the end of August; most rapidly along the eastern slope of the basin and in the Bay of Fundy, where Mavor (1923) records an increase in the 100-meter temperature from 3.92° on June 15 to 6.13° on September 7, 1919.[33]

TEMPERATURE AT 150 METERS AND DEEPER

Annual variations in temperature have proved wider than the regional differences at depths greater than 100 to 150 meters; nor has the regional distribution at different levels been parallel from summer to summer. The following table shows the western, central, and northeastern deeps of the basin fractionally warmer than its eastern side in August, 1913.

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[32] The 100-meter temperature was 5.96° on July 25, 1915, at station 10229.

[33] At *Prince* station 3, about 10 miles southeastward from the western end of Grand Manan.

Station	Depth, meters	Locality	Temperature, ° C
10088	183	Offing of Cape Ann	6. 28
10090	183	Center of gulf	6. 61
10092	183	Eastern arm of basin	6. 11
10100	183	do	6. 22
10093	219	Near German Bank	5. 89

In August, 1914, however, the bottom water was appreciably warmer (7° to 7.9°) in the eastern and northeastern parts of the basin than in the western and central parts (6° to 6.24°), apparently banking up against the Nova Scotian slope, as indicated on the chart (fig. 57). Successive stations, from the offing of Cape Ann to the Nova Scotian slope, again showed a slight rise in the temperature of the of the bottom water (at 175 meters) from west to east across the basin on August 31 to September 2, 1915, as follows: Station 10307, 5.4°; station 10309, 5.8°; and station 10310, 6.8°. The amount by which the temperature of the one side of the gulf differs from that of the other, in this stratum, varies so widely from year to year that it would not be surprising to find it virtually uniform over the whole area of the basin in some future summer.

Other features of the temperature at 175 meters worth mention are its constancy in the southwestern part of the basin from July 19 (station 10214, about 5.4°) to August 23 (station 10256, 5.6°) in 1914, and the fact that the southeastern part was warmer than the Eastern Channel in that summer,[34] although the latter offers the only route by which water of high temperature can flow into the gulf from offshore. Barring the possibility of higher temperature in one or the other sides of the channel than in its center, where the observations were taken, the most reasonable explanation for this apparent anomaly is that a considerable indraft had taken place late in June, but that this had then slackened, allowing the temperature of the channel to be reduced slightly by mixture with the cooler water to the east and west of it.

Our data for 1914, combined with temperatures taken south of Marthas Vineyard by Libbey (1891) in 1889, show the water along the continental edge abreast of the gulf as 10° to 11° at the 175-meter level in late summer, warming to 12° a few miles farther offshore (fig. 57). In 1914 the mouth of the Eastern Channel marked a division at this and greater depths between these comparatively high temperatures to the west and lower temperatures to the east, with the isotherms swinging offshore, abreast of Browns Bank, and a 175-meter value of only about 7.7° in the offing of Shelburne on July 28 (station 10233). But with the temperature between 11.3° and 11.85° there at this same level and at about the same date a year later (Bjerkan, 1919, p. 393; *Acadia* station 41), the ocean water was evidently closer in to the slope—annual variation sufficient to exercise considerable biologic effect on the bottom fauna along the southeastern slopes of Browns Bank and Georges Bank.

Only a small portion of the basin of the gulf is deeper than 175 meters. The bottom of the western bowl, at 260 meters (entirely inclosed at this level), was 7° in August, 1914, that of the eastern branch ranging from about 6° in its western

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[34] Station 10225 about 8.8° and station 10227 about 7.1° at 175 meters on July 23 and 24, 1914.

side (station 10249) to about 8° in its northeastern side off Machias, Me. (station 10246), with 7.9° recorded for the southeastern part of the basin (station 10225) and about 7° on the floor of the Eastern Channel (station 10227) that July.

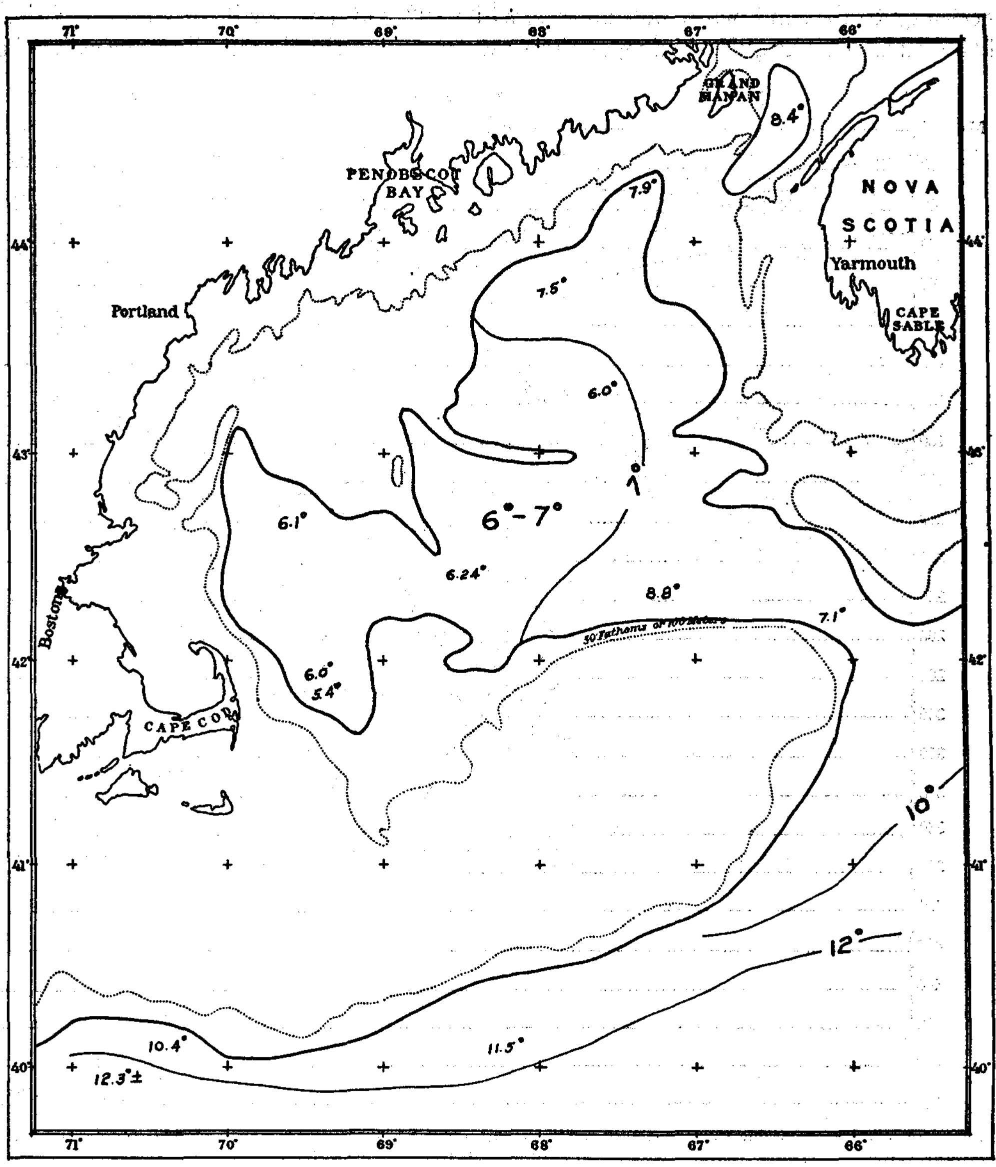

FIG. 57.—Temperature at a depth of 175 meters within the gulf for August, 1914. The temperatures along the continental slope are for July and August of that year, combined

PROFILES

The most striking thermal feature of the western side of the gulf in summer—certainly the one most often commented on—is its low temperature below the 40 to 50 meter level, contrasted with the warm surface water and with the still warmer oceanic water outside the edge of the continent to the south, illustrated more graphically in profile (fig. 58) than in horizontal projection. To find water on the continental slope along this profile as cold as the 100-meter reading in the gulf it is necessary to descend below 500 meters, while 10° water was within 40 meters' depth of the surface in the gulf but deeper than 180 meters on the slope. Farther east, where the basin to the north of the banks is warmer and where a cool wedge intervenes between ocean water and continental edge, a July profile (fig. 59) shows a contrast of only about 1° between the gulf, on the one hand, and the continental slope, on the other, at depths greater than 120 meters.

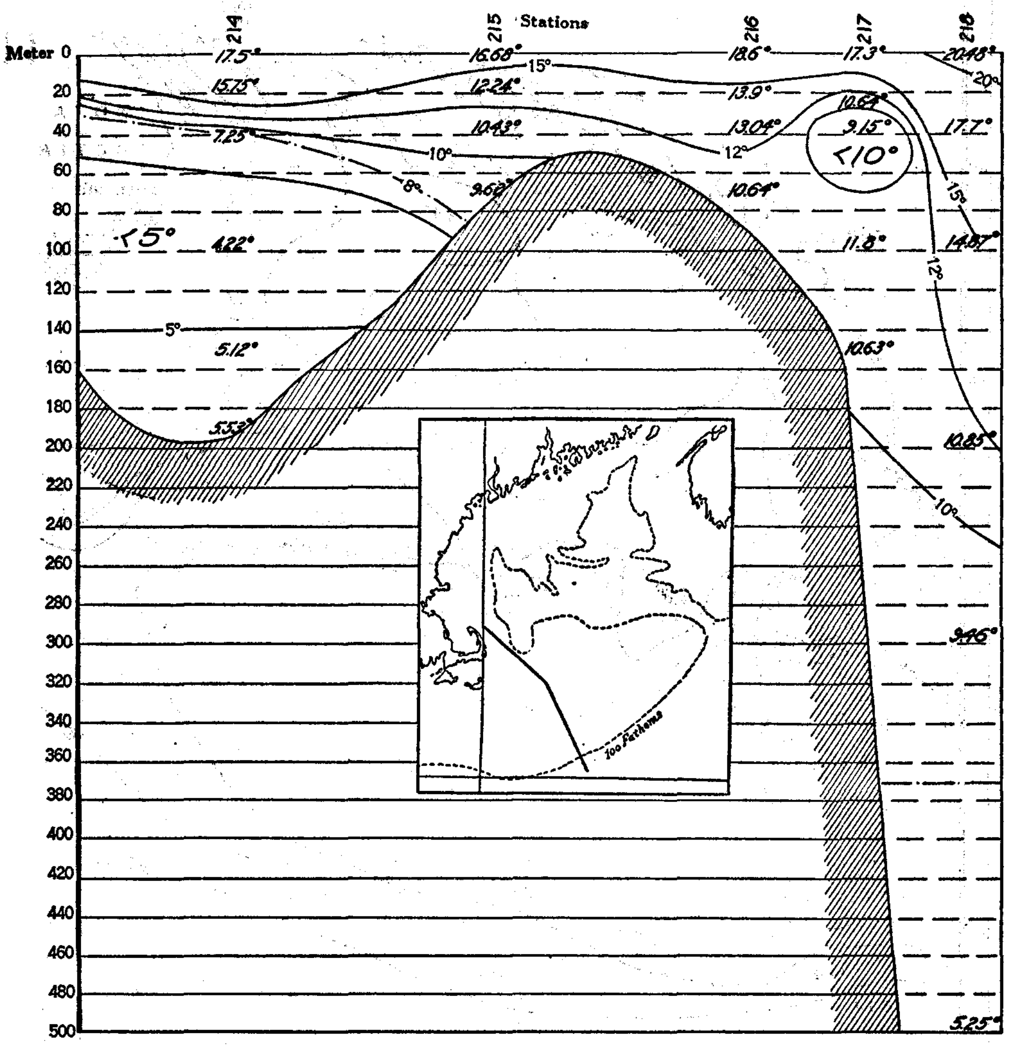

FIG. 58.—Temperature profile running from a point off northern Cape Cod, southeastward across Georges Bank to the continental slope, for July 19 to 21, 1914 (stations 10213 to 10218)

These two profiles of Georges Bank are further interesting for outlining the band of cool water that then extended along the bank from northeast to southwest, as just described. On the western member of the pair (fig. 58) this appears as a core (10°) over the offshore edge at a depth of 30 to 80 meters, but as a body of cold bottom water (8°) well in on the bank on the eastern profile (fig. 59), with the column of water nearly homogeneous in temperature from surface to bottom (inclosed by isotherms for 10° and 12°, evidence of active tidal mixing) on the northeastern part.

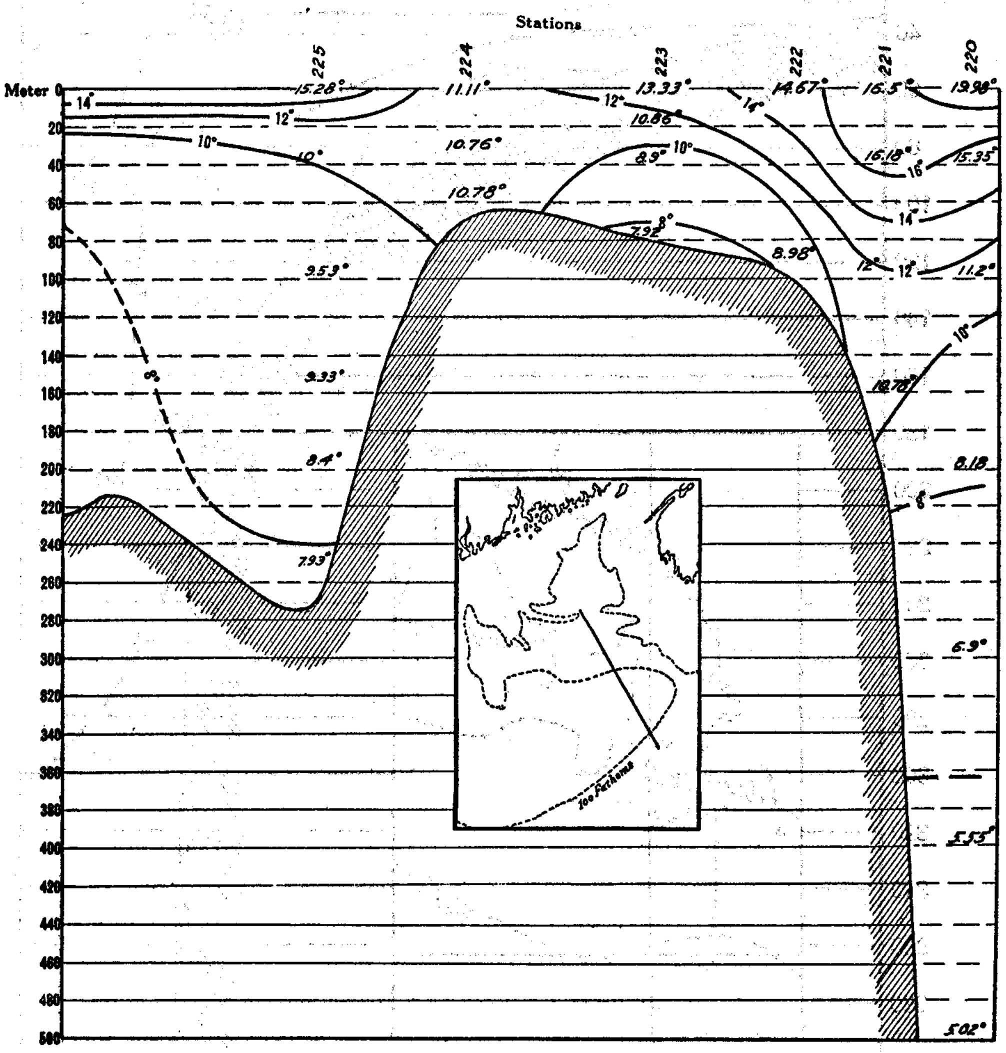

FIG. 59.—Temperature profile running from the eastern side of the basin, southeastward across the eastern end of Georges Bank to the continental slope, July 22 to 23, 1914 (stations 10220 to 10225)

With the August profile crossing the shelf off Marthas Vineyard (fig. 60), they also afford an instructive demonstration of the continuity of the zone of warm bottom water (10°) all along the offshore slope of Georges Bank at the 100 to 150 meter level in summer (though not farther east), with lower temperatures on the shoaler bottom of the bank, on the one hand, as well as deeper down the slope, on the other.

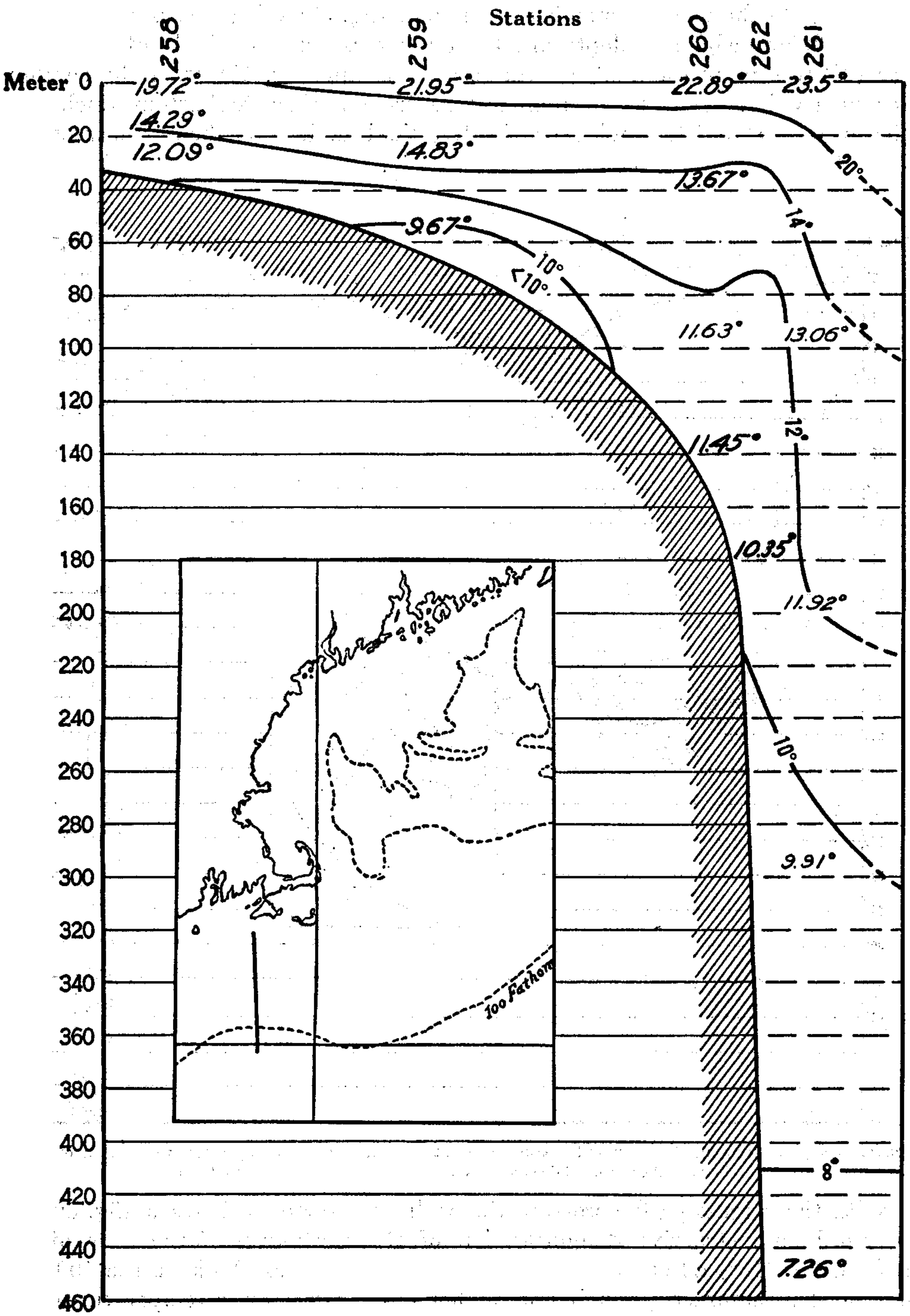

FIG. 60.—Temperature profile running southward from the offing of Marthas Vineyard to the continental slope, August 25 to 26, 1914 (stations 10258 to 10262)

The spacial relationship which the comparatively warm bottom water of the gulf bears to the colder mid stratum, to the still colder Nova Scotian water, and to the warm surface water, in summer, may best be illustrated by profiles crossing the Eastern Channel (fig. 61), crossing the gulf from west to east (figs. 62 and 63), and running out normal to the general trend of the eastern coast line of Maine (fig. 64).

The first of these, in conjunction with the corresponding profile for March (fig. 19), is especially interesting for its demonstration that it coincided with a slack period when a counter drift out of the gulf had filled the western side of the channel with colder and less saline water, but followed an inward pulse that had overflowed Browns Bank, raising the temperature of the whole column there to the high figure (8.5° to 14.7°) stated on the profile (station 10228). This, however, had spread no farther north—witness the lower values in the Northern Channel (station 10229) and the still colder water (3° to 10°) at the Cape Sable end of the profile (station 10230).

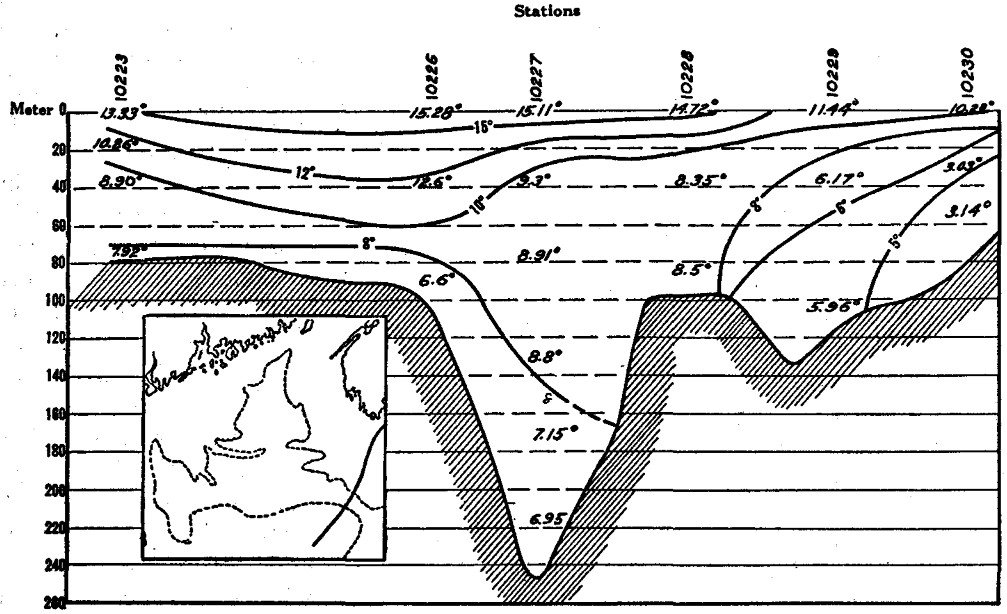

FIG. 61.—Temperature profile running from the eastern end of Georges Bank, across the Eastern Channel, Browns Bank, and the Northern Channel, to the offing of Cape Sable, July 23 to 25, 1914

Our summer cruise of 1914 does not afford a satisfactory profile across the gulf for July or August, lacking serial observations along the eastern slope of the basin, where the axis of warm bottom water, drifting into the gulf, is to be expected. One running eastward from the mouth of Massachusetts Bay toward Cape Sable for August 31 to September 2, 1915 (fig. 62), however, will represent the late summer state equally well for the gulf as a whole in a moderately warm year. The spacial relationship there shown between the warm surface water in the western side of the gulf (>16°), the cold mid stratum centering at about 100 meters (close to 5.5°), the warmer slope water (>6°) banked up against the eastern slope of the basin at depths greater than 140 meters, and the homogeneous column (9° to 10°) on German Bank in the

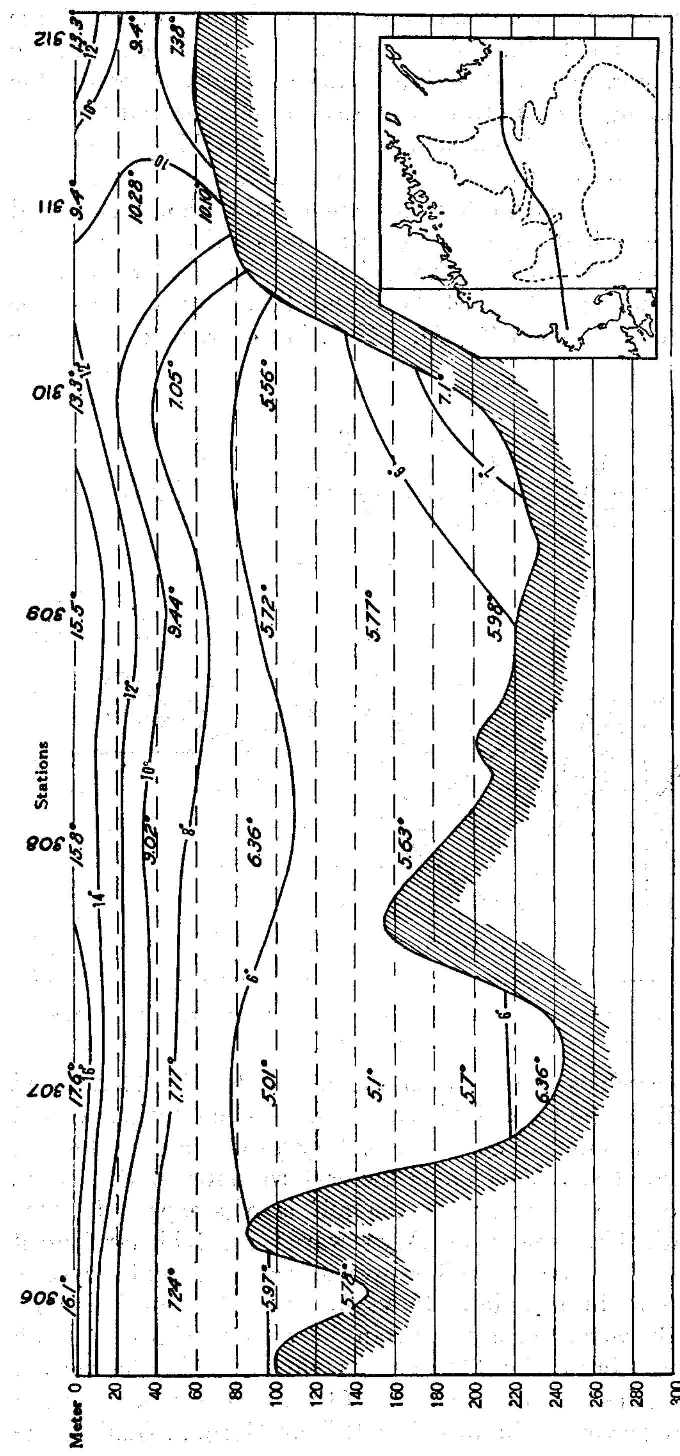

FIG. 62.—Temperature profile from the mouth of Massachusetts Bay to the offing of Cape Sable, August 31 to September 2, 1915 (stations 10306 to 10312)

eastern side of the picture (station 10311), resulting from the active tidal stirring, is characteristic of late summer.[35]

The low surface reading of 9.4° on German Bank was unexpected, because the whole underlying column and the surface water to the east as well as to the west of the station were slightly warmer. Probably this local chilling had its source in some upwelling from the still colder bottom water close in to Cape Sable.

In summers following periods when the inflowing bottom current has been weaker, or at least less regular (1913, for instance), cross profiles of the gulf bring out the cold mid layer even more clearly (fig. 63), with minimum readings of about 5.2° in both sides of the gulf at depths of 75 to 90 meters in this particular year. But, contrasting with this same month of 1914 and of 1915, the profile for 1913 shows only a fractional warming with increasing depth, from this level downward toward the bottom, with no apparent banking up of the warmer bottom water against the eastern slope.[36]

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[35] The isotherm for 10° for this region, on my earlier representation of this profile, is incorrect (Bigelow, 1917, fig. 71).

[36] Highest value at 175 meters 6.6° off Cashes Ledge (station 10090); lowest 5.9° in the eastern side of the basin (station 10098).

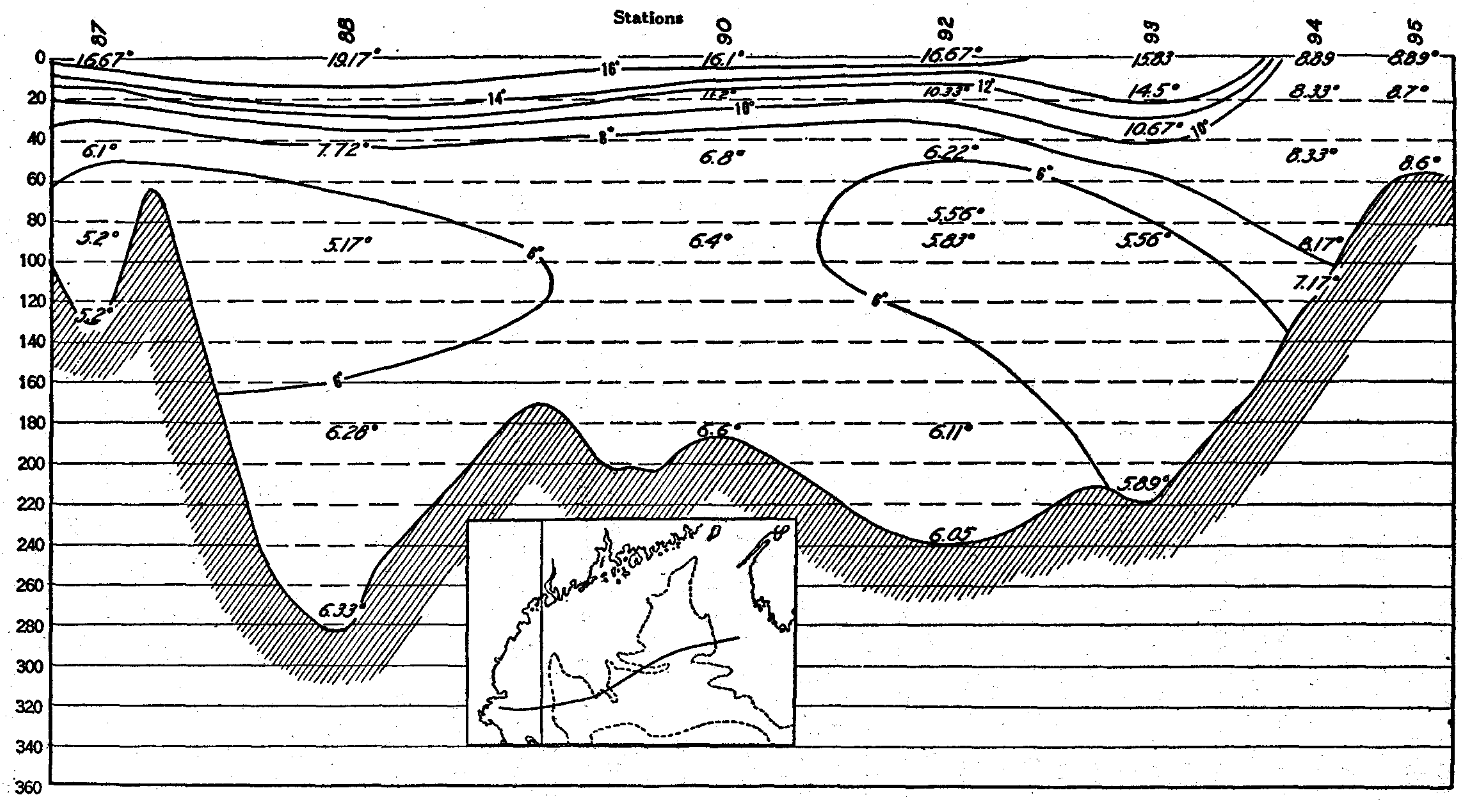

Fig. 63.—Temperature profile from the mouth of Massachusetts Bay to German Bank, August 9 to 20, 1913 (stations 10087, 10088, 10090, 10092 to 10095, and 10106)

The upper layers of the gulf thus present much the same picture from summer to summer when studied in west–east cross section, with isotherms closely crowded in the western side but spreading over the eastern coastal bank, and the uppermost stratum cooling from west to east as already described (p. 588). Invariably, too, the gulf has proved at least as cool at 100 meters as at any level in July and August, and usually coolest there in the form of a definite layer of minimum temperature spreading seaward, centripetally, from the western and northern shores. However, the spacial distribution of temperature at depths greater than 150 to 175 meters varies from summer to summer, depending on the volume and velocity of the bottom current drifting in through the Eastern Channel at the time or shortly previous (p. 613), as well as on the precise route followed by this water within the gulf. When this current has been in large volume shortly previous, it tends northward and westward around the eastern and northern slopes of the basin, so that the conditions described for 1914 and 1915 prevail (fig. 62). Following a long slack period, a reproduction of the temperatures of 1912 or of 1913 may be expected.

A composite profile (fig. 64), based on observations taken in the summers of 1913, 1914, and 1915, illustrates the relationship which the western extension of the warm bottom current bears to the shoaler water along the coast of Maine, on the one hand, and to the central part of the basin, on the other. When this drift is active, it hugs the northern slope of the basin as it eddies around to the westward, a statement supported by the evidence of salinity as well as of temperature.

The much lower surface temperature (12°) at the inshore end of this profile than over the basin offshore (16°) is simply the result of active vertical circulation along the coast; so, too, is the reverse relationship prevailing at the 60 to 100 meter level. I may also point out that this profile, like those already discussed, shows the cold mid-layer (of 5.3° to 6.04° at 100 to 150 meters) characteristic of the inner parts of the gulf in most summers, and which is reminiscent of the low temperature to which the whole mass of water shoaler than this had been chilled during the preceding winter (p. 689).

The maintenance of comparatively high temperatures down the slope, at depths greater than 30 meters, which is probably characteristic of the summer season in this part of the gulf, may have some biologic importance by making an especially favorable environment for such bottom animals as prefer a moderate temperature within narrow limits where they would find no sudden thermal bar to vertical migration.

Profiles crossing the mouth of Massachusetts Bay fron Cape Ann to Cape Cod, for the cold July of 1916 (fig. 65) and for August 22 of the warm summer of 1922 (fig. 66), are introduced for graphic demonstration of the thermal stratification that develops there by the end of the summer. It is surely worth emphasis that the bottom temperature should be only between 4° and 5° in water as shoal as 75 meters in as low a latitude as 42° N. at the end of August, with a surface temperature as high as 18°, as was the case in 1922—and this in a warm year.

The presence of a surface stratum of homogeneous water (18.6° to 18.7°) nearly 10 meters thick, blanketing the northern part of the August profile (station 10633), is rather contrary to our previous experience in this part of Massachusetts Bay, where low surface temperature usually has been recorded, reflecting upwellings or tidal mixings; but a temperature gradient of this type would result from active stirring of the upper stratum, if there be little interchange of water between the latter and the deep strata. In Cape Cod Bay, where partial inclosure and shoal water make local warming more effective than in any other part of the gulf, this state is probably typical of midsummer, judging from the state of the upper 14 meters of water there (18.3° to 17.9°) on August 24, 1922 (station 10644 and 10645, p. 995). The fact that the superficial stratum of water warmer than 12° was considerably thicker near Cape Cod than in the center of the bay that August corroborates the station data for May and June, 1925, to the effect that Cape Cod Bay is an important center of production of warm water during the summer months. Had the profile been run a few miles farther west, water warmer than 18° probably

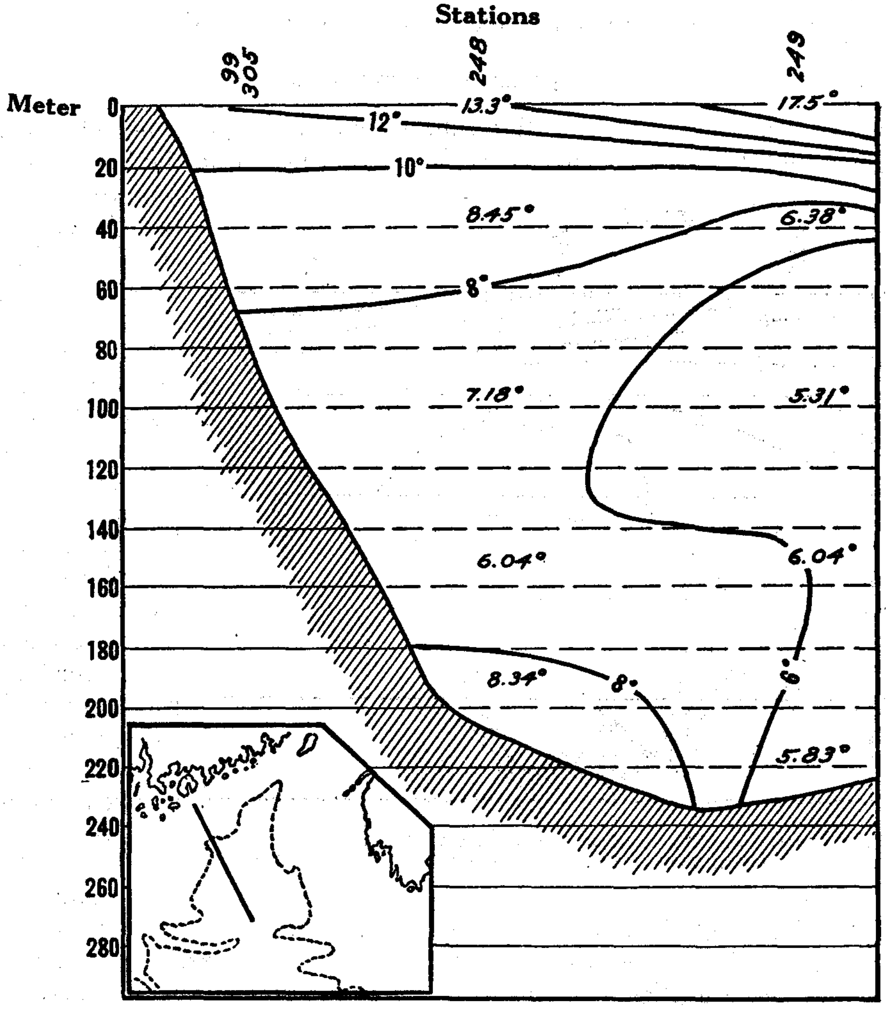

FIG. 64.—Temperature profile running southward from Mount Desert to the basin for August, from the data for the years 1913, 1914, and 1915, combined (stations 10099, 10248, 10249, and 10305)

would have occupied the upper 10 meters from end to end, instead of showing the chilling effect of the strong tides, which actually characterize its Cape Cod end.

In the July profile (fig. 65) the cold bottom water is banked up against the southern side of the bay, but against the northern side on the profile for August (fig. 66). A difference of this sort probably reflects a corresponding difference in the movements of the deep water around Stellwagen Bank. Judging from experience in other years, the state illustrated by these August stations is the more usual in summer.

BOTTOM TEMPERATURE

The bottom temperature of the gulf in summer is governed chiefly by the depths, but also to some extent by locality. At this season the bottom is coldest (3° to 5°) in the troughs off the western shore of the gulf, irrespective of depth, and in the offing of Cape Sable in the opposite side, with the whole deep basin 1° to 3° warmer outside the 150-meter contour (5° to 8°). For example, an animal living in the trough off the Isles of Shoals might actually suffer lower temperatures during some summers than in some winters or springs, according as the years be cold or warm in the gulf. The annual differences in the basins at depths greater than 175 to 200 meters consequent on irregular pulses in the bottom current may so overshadow the regular seasonal cycle as to make the latter negligible, biologically, up to the end of the summer. Bottom dwellers in the coastal zone, however, must be inured to a wide range of temperature if they are to survive; as, indeed, they must in shallow boreal waters in general.

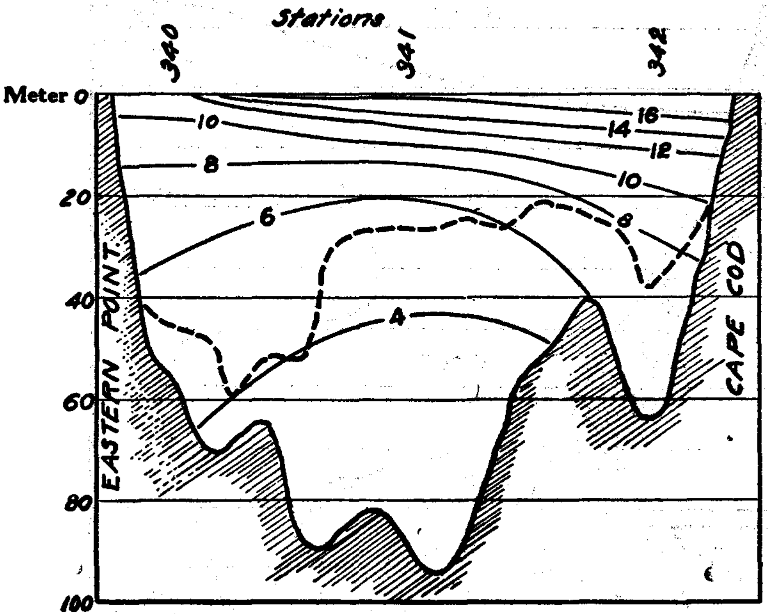

FIG. 65.—Temperature profile crossing the mouth of Massachusetts Bay just west of Stellwagen Bank, July 19, 1916 (stations 10340 to 10342). The contour of the bank is represented by the broken curve

Cape Cod Bay experiences a wider fluctuation in bottom temperature, with the succession of the seasons, than any other part of the open gulf outside the estuaries and islands. In order to exist there, without bathic migration, in water shoaler than 5 to 10 meters, any animal must be indifferent to temperatures as high as 18° to 19° in midsummer (p. 623). A bottom temperature of 17.9° was even recorded as deep as 13 meters off Barnstable on August 24, 1922 (station 10644)—an extreme for which the exposure of the neighboring flats to the sun at low tide is no doubt responsible—with 13.2° at 18 meters off Plymouth (station 10642). In winter these same regions cool to 0° or even fractionally colder. Around the more exposed shores of Massachusetts Bay, however, we have found the bottom temperature 12° to 9.8° in 15 to 18 meters depth; 7° to 9.8° at 25 to 30 meters; 7.2° to 5.6° at 40 to 50 meters; and 4.5° to 6.2° at 65 to 75 meters in August.

Compare this with the Bay of Fundy, where even the littoral zone warms only slightly above 10° to 12° off open shores, but where the bottom in 40 to 50 meters is almost equally warm by the end of the summer (p. 599). Under these conditions cool-water animals, at home in temperatures up to 10°, find no limit to their bathic dispersal short of the surface, instead of being confined to depths greater than 12 to 15 meters, as they are in Massachusetts Bay in summer. On the other hand, any animal restricted physiologically to truly Arctic temperatures would find a more favorable habitat in the deeper parts of Massachusetts Bay and in the still colder trough off the Isles of Shoals than in the Bay of Fundy at any depth.

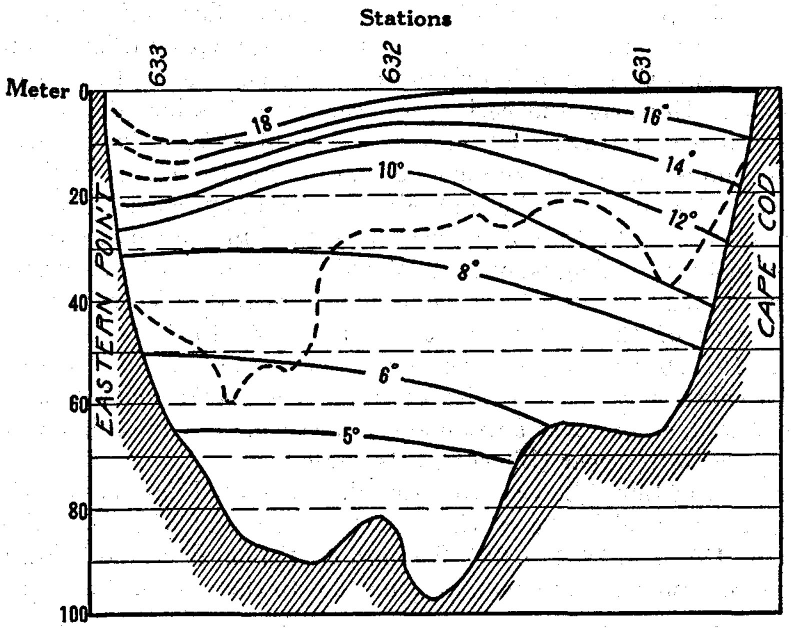

FIG. 66.—Temperature profile crossing the mouth of Massachusetts Bay from Gloucester to Cape Cod, August 22, 1922 (stations 10631 to 10633). The broken curve represents the shoalest contour of the bottom along the rim formed by Stellwagen Bank

The studies on the life history of the cod, on which the Bureau of Fisheries is now engaged, lend special interest to the bottom temperatures on the grounds where most of the fish have been tagged—Nantucket Shoals, Platts Bank, and the vicinity of Mount Desert Island.

In August, 1925, the *Halcyon* had bottom readings of 11.2° to 15.56° on the shoals in depths of 20 to 30 meters (p. 1012), and probably this is about the maximum to be expected there in an average summer. On the other hand, the bottom water cools to about 3° to 4° there at the end of winter, so that any fish (or other animals) remaining the year round on the shoals may experience a difference of 11° to 12° with the change of the seasons.

The bottom temperature usually has ranged from 9° to 10° in about the same depth of water off Mount Desert Island in August, but in the cold summer of 1923 it was probably about 2° colder there, judging from a temperature of 7.5° at the 30-meter level a few miles farther out from shore on August 5 (p. 599). On Platts Bank the bottom water had warmed only to about 6° at a depth of 71 meters by September 3, in 1925, with 4.5° at 80 meters on the 20th of July (p. 1012); but I may anticipate by pointing out that the temperature there does not reach its maximum for the year until October or even later at depths so great.

ANNUAL VARIATIONS IN SUMMER TEMPERATURE

Although the temperature of the gulf shows wide fluctuations with the change of the seasons, our data for seven summers, together with earlier records (p. 514), prove that as a rule there is little difference at a given locality, from year to year, for a given month. However, the period of observation has included the notably cold summers of 1916 and 1923; such also was that of 1882. Conversely, it is to be expected that unusually warm summers do also occur from time to time, though no definite record of such has yet been obtained in the temperature of the gulf.

On the whole, the bottom of the western side of the gulf had virtually the same temperature in July and August of 1872 (Verrill, 1874 and 1875) as when deep readings were first taken there[37] in these same months of 1912. Verrill's readings for the northeast corner of the gulf were consistently 0.5° to 1.5° colder in 1873 and 1874 than in 1912, but correspond very closely with the state of that region in 1913. The surface values for 1873 likewise correspond as closely with those for 1912 as could be expected, except that autumnal cooling seems to have commenced earlier in the season in the latter year (Bigelow, 1914, p. 92).

The summer of 1882 (the year that saw the oft-quoted destruction of the tilefish) was colder than normal in the southern parts of the Gulf of Maine, where the *Fish Hawk* (Verrill, 1882 and 1884, p. 654; Tanner, 1884b) obtained the following readings, with reliable reversing thermometers, on bottom to the eastward of Cape Cod:

Depth, meters	Temperature	Depth, meters	Temperature
	°C.		°C.
51	4.4	111	2.8
60	3.9	152	3.3
80	3.9	166	3.3
100	2.8	201	3.6

Turning now to the more recent records, we find the August temperatures for 1912, 1913, 1914, and 1923 differing so little, one from another, at any level that they may be taken as typical for that month.

The slight differences between the first three of these years have been discussed in earlier reports (Bigelow, 1915, p. 246; 1917, p. 231). Briefly, the eastern part

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[37] These early readings and the allowance that must be made for the inaccuracies inherent in the type of thermometer used are discussed in detail in an earlier report (Bigelow, 1914, p. 92).

of the gulf was slightly colder, the western half slightly warmer, in the summer of 1913 than in 1912, though the greatest annual difference was nowhere greater than 2.5° for sets of observations taken at nearly the same date. Thus we found the August stations in Massachusetts Bay agreeing very closely for these two years (stations 10044, 10045, and 10106). The water a few miles north of Cape Ann was about 1° to 2.5° warmer in August, 1913 (stations 10104 and 10105) than in July, 1912 (stations 10011 and 10012b), a difference that may have been due chiefly to a difference in the dates at which the readings were taken.

The surface of the western side of the basin was about 1° warmer, the 100-meter level about 0.5° warmer, and the 200-meter level about 1.5° warmer on August 9, 1913 (station 10088), than on July 15, 1912 (station 10007); and while this difference was seasonal in the shoal strata, it probably reflected an annual fluctuation at depths greater than 100 meters. Off Platts Bank, a few miles to the northward, observations taken within three days of the same date (7th of August in 1912, station 10023; August 10 in 1913, station 10091) showed the immediate surface about 1° colder in 1913 than in 1912. However, this may have been due to a difference in the stage of the tide, which runs strong over the bank. The bottom temperatures there were almost precisely alike for the two years. In the eastern side of the basin 1913 was slightly the warmer year down to 70-odd meters, but about 1.5° the colder from that level down to bottom at stations only a few days apart in date.

The fact that the water was more than 2.5° warmer on the surface near Monhegan Island on August 14, 1913 (station 10102), than on August 2, 1912 (station 10021), though with virtually no difference below the 30-meter level, can hardly be accounted for on a seasonal basis. The mean temperature for the whole column of water was also about 0.7° higher on Jeffreys Bank, off Penobscot Bay, on August 2, 1913 (station 10091, about 10°), than on the 8th in 1912 (station 10025, about 9.3°), with less active vertical circulation, as evidenced by a wider vertical range of temperature. The 1913 temperatures, however, were about 0.75° to 1.5° the lower a few miles farther east on August 14 (station 10038, 1912; station 10101, 1913). The August temperatures for 1913 were likewise 1° to 1.5° the colder along the eastern coast of Maine and over the coastal bank west of Nova Scotia, where the observations for the two years were taken within a few days of the same dates. For example, the station off Lurcher Shoal was about 1° colder at the surface and in the mid levels, about 2° to 3° colder near bottom at 120 to 140 meters depth, in 1913 (station 10096) than in 1912 (station 10031); German Bank was also about 2° colder at all levels.

Except for the immediate surface, so subject to seasonal change, the upper 100 meters of the western basin was warmer in 1915 than in any previous summer of record; below that depth the readings for that year were fractionally cooler than those for 1913 or 1914, but warmer than for 1912, with an extreme annual variation of about 2.4°.

The surface stratum of the center of the gulf near Cashes Ledge was 2° to 3° warmer in 1914 than in 1913, but the water deeper than 40 meters was as much colder, with temperatures for 1915 intermediate between these two years at depths greater than 80 meters. These differences may have been due to differences in vertical circulation around Cashes Ledge, however, as may the fact that the water was coldest here on bottom in 1915.

In the western side of the eastern arm of the basin the differences in temperature between the four summers were less than 1°. On German Bank the temperature was about 1° higher in 1914 than in 1913, but about the same as in 1915 (allowing for seasonal differences, due to the difference in date of the observations).

The temperature along the northeastern coast of Maine, in the one side of the gulf, and in the deep bowl off Gloucester, in the other, have varied but little from summer to summer; but the deep water was 1° to 2° colder next the land west of Penobscot Bay and off Cape Elizabeth in 1914 than either in 1912 or in 1913. This also applies at depths greater than about 75 meters to the trough between Jeffreys Ledge and the coast.

In the deep strata of the Bay of Fundy the bottom water ranged about 2° warmer in August, 1914 (Craigie, 1916a), than in the summers of 1915 (Craigie and Chase, 1918) or 1916 (Vachon, 1918), and slightly warmer than Mavor (1923) records it for 1917 or 1919.

These annual differences may be summarized as follows: Except for the immediate surface, the upper 150 meters was slightly colder in the western, central, and northern parts of the gulf in 1914 than in either of the two preceding years, but the bottom water of the western, northern, and eastern parts of the basin were warmer, with still higher temperatures in the western side in 1915.

More or less fluctuation in summer temperature is to be expected in any partially inclosed basin as subject to violent climatic changes as is the Gulf of Maine, and where waters of different temperatures meet. What really deserves emphasis is that the yearly changes have been very small during the period of record; certainly not enough seriously to affect the waters of the gulf as a biologic environment, except perhaps in 1916.

During that year vernal warming proceeded so slowly in the sea, after an almost Arctic winter and a tardy spring, that the temperature of the central part of Massachusetts Bay was only 3.67° to 3.9° at 50 to 80 meters depth on July 19 (station 10341), though the immediate surface was about as warm as the expectation for that date (16° to 17°). In fact, the deep readings were hardly warmer than readings taken in May of the preceding year, only about 1.5° warmer than the winter minimum for that level during 1913, and 2° warmer than the early March temperature of 1920 (p. 522). The water off Northern Cape Cod (stations 10344 and 10345)[38] was likewise decidedly colder in 1916 than in the summers of 1913 to 1915, with the 20 to 40 meter lever 2° to 3° colder than in 1913 and 6° to 9° colder than in the same month of 1914. The suprisingly low surface temperatures of 10° off Chatham and 7.2° in the southwestern part of the basin on July 22, 1916, contrast with 16° to 17° for this part of the gulf as a whole at about that same date in 1913 and 1914. It is clear that such cold surface water reflected some temporarily and locally active vertical circulation, because the vertical range of temperature was less than 1° between the surface and 30 meters at the coldest of these two stations (10346), instead of a range of about 9°, which previous experience suggests as normal for the western side

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[38] About 4.1° at 50 meters, 3.85° at 100 meters, and warming fractionally below that level to 4.06 at 150 meters.

of the gulf in July. But even allowing for this factor, a considerable annual difference in surface temperature remains to be accounted for between the cold July of 1916 and the warmer years, 1913 to 1915.

Furthermore, the vertical warming below 100 meters, so characteristic of this side of the gulf in 1914 and 1915 (Bigelow, 1917), was hardly appreciable in 1916. During the interval, July 22 to August 29, the mid layers off northern Cape Cod warmed by about 1° or 2° (stations 10344 and 10398). Even then, however, the temperature did not equal that of 1912 on the same date (station 10043, August 29), or of 1913 three weeks earlier (station 10086, August 5; Bigelow, 1922, p. 91).

The surface water on the northwestern part of Georges Bank was also about 2° colder in July, 1916, than in that month of 1913 or of 1914, as appears from the following table:

Depth	July 9, 1913, station 10059	July 20, 1914, station 10215	July 23, 1916, station 10347	Depth	July 9, 1913, station 10059	July 20, 1914, station 10215	July 23, 1916, station 10347
	° C.	*° C.*	*° C.*		*° C.*	*° C.*	*° C.*
Surface	13.33	16.68	11.39	40 meters		10.43	
20 meters		12.24		55 meters	12.60		
27 meters	12.60			60 meters			9.61
30 meters			10.91	70 meters		9.62	

The difference in temperature between July of 1916, on the one hand, and of 1913 and 1914, on the other, was even wider along the southern edge of the bank. Violent annual, even day by day, fluctuations are to be expected there (Bigelow, 1922, p. 10), but nothing in our previous experience foreshadowed summer temperatures as low as those of 1916, when the bottom water was 4° colder there than in 1914, though the stations for the two years were close together in location and the surface temperatures (17° to 18°) were almost alike. The surface near the continental edge south of Nantucket lightship and the depths greater than 50 meters were likewise 3° to 4° colder in July, 1916 (station 10351), than in that month in 1913 (station 10061); and the cold band just outside the edge was 4° to 5° (fig. 67) instead of 9° to 10°, as we had found it in 1914 (fig. 58).

There is nothing unprecedented in a vertical distribution of temperature of the type shown on this 1916 profile (fig. 67) over this part of the slope; indeed, its repeated occurrence suggests that something of the sort is to be expected except when obscured by encroachments from the warm water of the so-called "Gulf Stream" (p. 608). The surprising feature of the summer of 1916 is that the temperature of the coldest layer should have been so low and that water so cold lay so close to the surface of the open sea in July at this latitude. In fact, as I have elsewhere noted (Bigelow, 1922, p. 103), this July temperature very closely paralleled the temperature taken at the same relative position on the slope off Cape Sable, about 200 miles to the northeastward, on June 24 of the year previous (station 10295).

The *Grampus* did not visit the eastern side of the gulf in the summer of 1916, where the water was also unusually cold during that summer, as Dr. A. G. Huntsman writes:[39]

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[39] Quoted from a letter from Doctor Huntsman.

The temperature of the water in the Fundy region was unusually low during the summer of 1916. The data given me by Craigie (1916a, 1916b), Craigie and Chase (1918), and by Vachon (1918) show that in the St. Croix River, near St. Andrews, and in Passamaquoddy Bay the temperature of the greater part of the water during the first half of August was approximately one degree (C.) lower in 1916 than in 1914. In the Bay of Fundy, off Campobello Island, the water

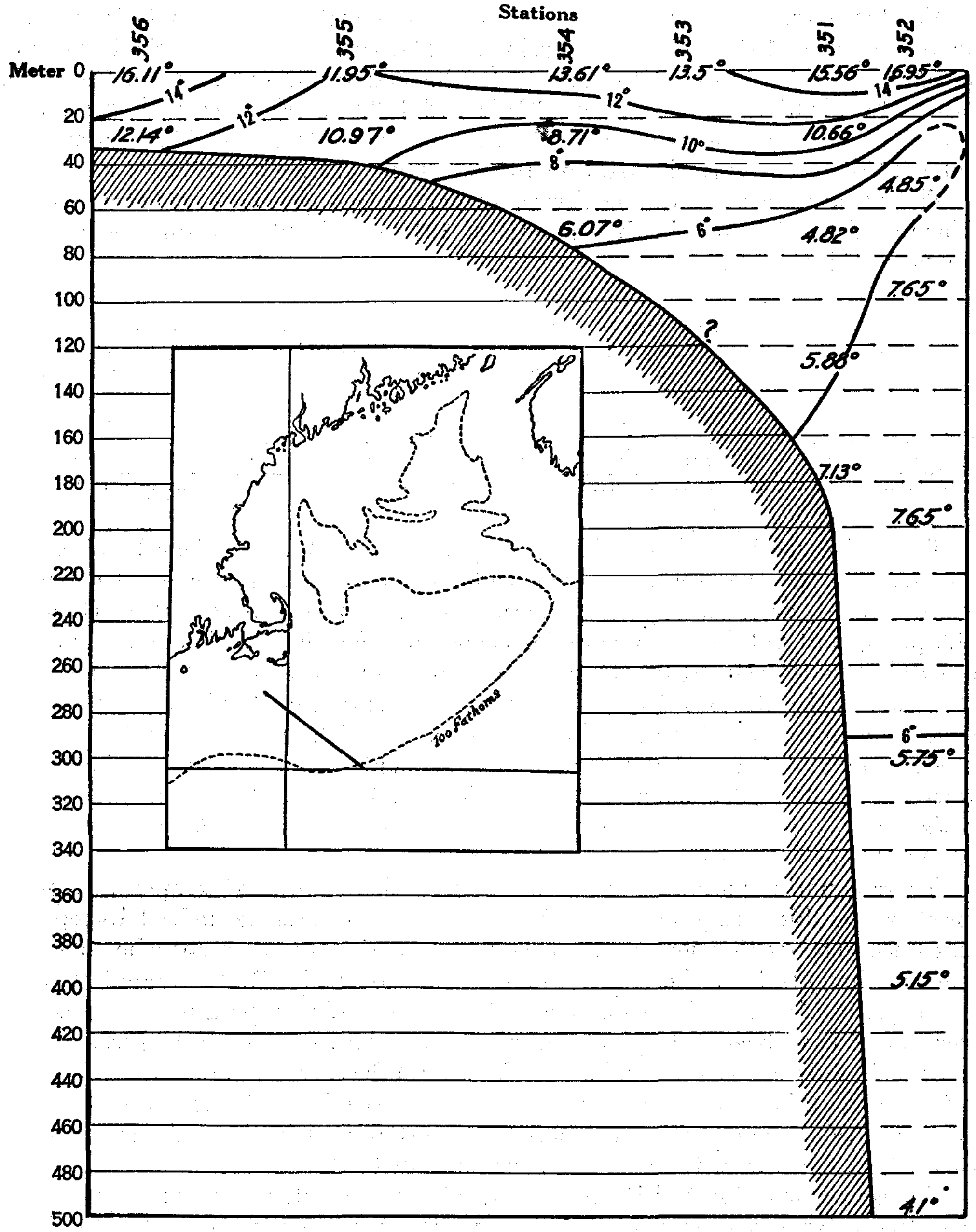

FIG. 67.—Temperature profile running southeastward from the offing of Nantucket to the continental slope of Georges Bank, July 24 to 26, 1916 (stations 10351 to 10356)

was slightly colder on July 25, 1916, than it had been on July 14, 1915, and nearly two degrees (C.) colder on August 16, 1916, than it had been on August 27, 1914. Also, in the Bay of Fundy, east of Grand Manan, the temperature of the body of the water was nearly one degree (C.) lower on July 24, 1916, than on July 15, 1915, and more than two degrees (C.) lower on August 16, 1916, than on August 27, 1914. This shows that in the Bay of Fundy the water was colder in the summer of 1915 than in that of 1914, and still colder in that of 1916.

Enough data have thus been gathered to class 1916 definitely as an abnormally cold year in the gulf.

It is interesting to consider whether climatic conditions during the preceding months will account for this abnormality. Unfortunately, no observations were taken in the gulf during the preceding winter, but the deep temperature of the western side changes so little from February to June that its July state gives an indication of the temperatures that have prevailed there in spring. Judged from this viewpoint, the July temperatures of Massachusetts Bay and of the neighboring parts of the gulf for 1916 do not suggest that the sea temperatures of the preceding winter were abnormally low.

This conclusion is corroborated by meteorological conditions, for the early part of the winter of 1915–16 was warmer than usual (mean temperature for January about 6.7° F. higher than normal at Boston, 2.7° F. higher than normal at Provincetown); but the temperature was about 2.5° F. below normal at Boston in February, 4.4° F. below normal in March, with unusually heavy snowfall in both these months (30.3 and 33.3 inches, respectively). Consequently, there is every reason to suppose that the temperature of the water of Massachusetts Bay did not commence to rise until a month or even two months later than usual that spring, and that vernal warming proceeded more slowly at first than in more normal years, because the weather continued abnormally cool and cloudy throughout May and June. Furthermore, it is in just such a spring as this, when the surface stratum warms very slowly at first, but then rapidly, that the deeper water is most effectively blanketed from the penetration of heat from above by the sudden development of a state of high stability. Indeed, a better illustration of how slowly the deeper water warms under such circumstances could hardly be found than by the very small rise in temperature that took place off Cape Cod from July 22 (station 10344) to August 29 of that year (10398) at 40 to 50 meters.

Thus the difference in temperature between the cold summer of 1916 and the warm summers of 1913, 1914, and 1915, in the western side of the gulf, was no wider than can be accounted for on the basis of the local weather.

I may point out that a cold winter and spring in 1916 were similarly followed by low summer temperatures in the coastal water all along the continental shelf, westward and southward to Chesapeake Bay during that same year (Bigelow, 1922), not alone in the Gulf of Maine.

It is possible that the low gulf temperatures of 1916 also reflected some unusual expansion of the Nova Scotian current, because even a temporary offshoot of that icy-cold stream crossing the gulf at any time during the spring would chill the surface of its western side 2° to 3° or more below normal (p. 680). Had the *Grampus* made a general survey of the gulf in 1916, as she did in 1914 and 1915, this question would have been cleared up; but the few stations for that cold year were all located close to the western shores. The salinity of the Nova Scotia current being considerably lower than that of the water it meets in the Gulf of Maine (p. 727), its presence causes low salinity as well as low temperature such, indeed, as prevailed at our few gulf stations for 1916. Salinity, however, is not a safe criterion for northern water in the western side of the gulf, because it is also dependent on the amount of run-off from the rivers, which was greater during the spring of 1916 (p. 837) than usual.

No serial observations were taken in the open gulf during the summers of 1917 to 1919, but Mavor's (1923) data for the Bay of Fundy classify 1917 and 1919 as normal seasons. Brooks (1920), however, points out that 1920 continued a "cold" year in the gulf through the summer, by the testimony of bathers along New England beaches. This was followed by a summer of at least average warmth in Massachusetts Bay, and probably over the gulf as a whole, in 1922 (p. 995). By contrast the summer of 1923, like that of 1916, was unusually cold in the deeper waters following a severe winter, with unusually heavy snowfall, and a tardy spring. Surface readings would not have suggested this more than a mile or two out from the land anywhere in the western side of the gulf. In fact, the coast sector between Cape Ann and Penobscot Bay was actually a degree or two warmer on the surface in 1923 than in 1912 at the end of the first week of August, as illustrated by the curves for 16° and 18° temperature on the charts for the two years (fig. 47), with readings of 16° and upwards right into the land off Cape Elizabeth in 1923, where we have usually found the coast skirted by a belt 1° to 3° cooler (p. 588).

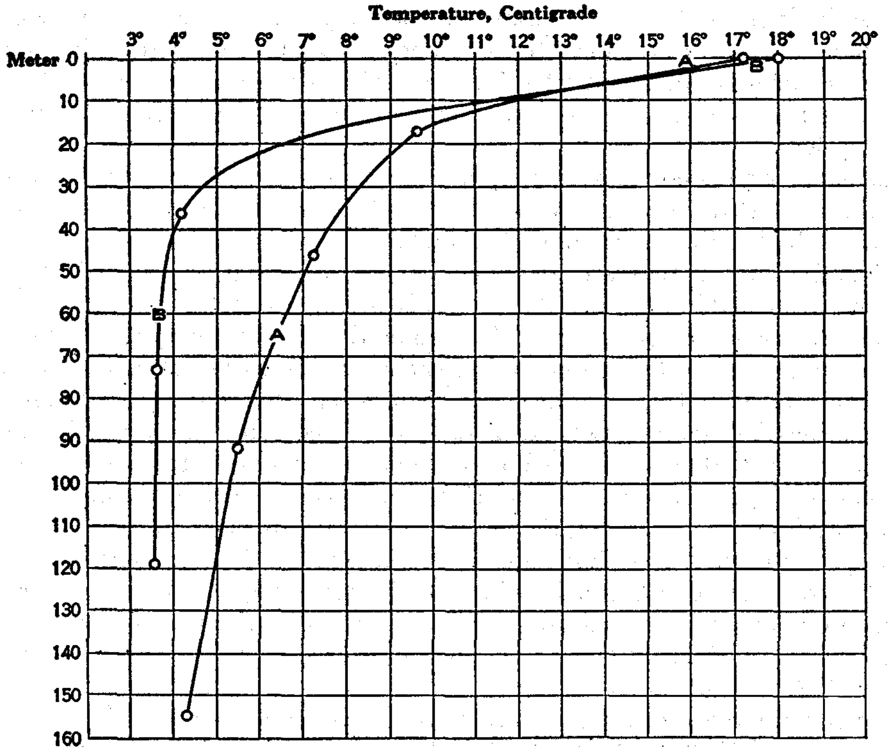

FIG. 68.—Vertical distribution of temperature off Cape Elizabeth on August 15, 1913 (A, station 10104), and on August 7, 1923 (B, latitude 43° 18', longitude 69° 44')

However, surface readings taken by the *Halcyon* to the eastward of Penobscot Bay early that August proved about 2° lower than the expectation. Bathers, too, reported the water unusually cold along the beaches throughout that summer, after offshore winds. This was corroborated by serial observations off Gloucester, which proved the whole column of water below the 30-meter level 1° to 3° colder in August, 1923, than it was three weeks earlier in the season even in the cold summer of 1916, although the difference in date would suggest just the reverse. Depths greater than 40 meters were also 1° to 3° colder off Cape Elizabeth in 1923 than in any previous August of record (fig. 68), notwithstanding the warm surface just mentioned. This statement would probably hold good for the inner part of the basin in general, also, as well as along the eastern coast of Maine, the relationship being similar near Mount Desert Island and off Mount Desert Rock (table, p. 635).

It is probable that a summer colder than those of 1916 or 1923 comes very seldom in the Gulf of Maine, because winters so severe, and with so heavy a snowfall, are exceptional (p. 697).

The possibility that cyclic changes of temperature may take place in the gulf, with warmer or colder periods enduring over many years, must not be ignored; but nothing of this sort has been recorded there within historic times.

The following comparative tables for representative localities will show in detail the annual differences in temperature summarized in the preceding pages.[40]

Annual differences in temperature

MOUTH OF MASSACHUSETTS BAY

Depth, meters	1912 10002 July 10	1913 10087 Aug. 9	1914 10253 Aug. 22	1915 10306 Aug. 31	1916 10343 July 19	1922 10632 Aug. 22	1923 Aug. 9
0	18.3	16.7	18.9	16.1	16.4	18.1	17.2
20	9.4	10.6	11.2	10.5	6.0	9.1	9.0
40	6.6	6.7	6.5	8.0	4.1	7.4	5.5
60	5.0	5.4	5.4	6.7	3.8	5.6	4.4
80	4.6	5.3	4.8	6.3	3.7	----------	3.3
100	4.6	5.2	4.6	6.2	----------	----------	3.2
120	----------	5.2	4.5	6.0	----------	----------	3.1
140	----------	----------	4.5	5.9	----------	----------	3.1

WESTERN BASIN

Depth, meters	1912 10007 July 15	1913 10088 Aug. 9	1914 10259 Aug. 22	1915 10307 Aug. 21
0	17.8	19.2	20.0	17.2
20	11.7	12.6	11.5	12.5
40	8.0	8.7	5.8	9.0
60	6.0	6.4	4.9	7.0
80	5.0	5.4	4.5	5.7
100	4.7	5.2	4.4	5.2
120	4.6	5.6	4.7	5.2
140	4.6	5.9	5.3	5.3
160	4.6	6.2	5.9	5.7
180	4.6	6.3	6.5	5.8
200	4.6	6.3	6.8	5.9
220	4.6	6.3	7.0	6.2
240	----------	6.3	7.0	6.4
260	----------	6.3	7.1	----------

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[40] As the readings were not taken at the same levels at all the stations, or at as many levels as it is desirable to show here, it has been necessary in many cases to derive most of the values by interpolation. The temperatures are approximate, therefore, and are given only to the nearest tenth of a degree, Centigrade.

Annual differences in temperature—Continued

CENTER OF GULF NEAR CASHES LEDGE

Depth, meters	1913 10090 Aug. 10	1914 10255 Aug. 23	1915 10308 Sept. 1
0	16.1	19.2	15.8
20	11.1	12.2	11.2
40	7.2	7.8	9.1
60	6.6	5.7	7.7
80	6.4	4.3	6.8
100	6.4	3.1	6.3
120	6.4	4.1	6.0
140	6.4	4.7	5.8
160	6.5	5.5	5.7
180	6.6	6.8	----------
200	6.6	----------	----------

TROUGH BETWEEN JEFFREYS LEDGE AND COAST

Depth, meters	1912 10011-12b July 17-23	1913 10104 Aug. 15	1914 10252 Aug. 15
0	15.0	17.2	16.2
20	8.3	9.6	12.0
40	6.1	7.8	7.8
60	4.8	6.6	6.2
80	4.6	5.8	5.0
100	4.6	5.2	4.3
120	4.6	4.8	3.8
140	----------	4.5	[1]3.7
160	4.1	4.3	----------
180	----------	----------	----------

[1] At 130 meters.

OFF CAPE ELIZABETH

Depth, meters	1912 10019 July 29	1913 10103 Aug. 12	1914 10251 Aug. 14	1923 Aug. 7
0	13.9	16.1	16.6	18.1
20	11.1	11.3	----------	----------
40	8.3	8.7	5.7	4.3
60	6.9	7.4	----------	3.9
80	5.8	6.1	----------	----------
100	5.7	6.7	4.4	3.6
120	----------	----------	----------	3.5
140	----------	----------	4.9	----------

OFF PENOBSCOT BAY

Depth, meters	1912 10039 Aug. 22	1913 10101 Aug. 14	1914 10250 Aug. 14
0	13.3	11.1	13.1
20	11.8	10.1	10.2
40	9.3	9.4	8.6
60	8.9	8.1	7.9
80	8.7	8.7	7.4
100	8.3	8.4	7.1
120	7.9	----------	6.6
140	7.3	----------	6.2

Annual differences in temperature—Continued

CLOSE IN TO BAKERS ISLAND, OFF MOUNT DESERT ISLAND

Depth, meters	1913 10099 Aug. 13	1915 10305 Aug. 18	1923 Aug. 5
0	12.8	10.8	11.7
25	10.0	9.4	7.6
40	9.3	----------	----------
50	----------	8.8	7.0

OFF MOUNT DESERT ROCK

Depth, meters	1913 10100 Aug. 13	1914 10248 Aug. 13	1923 Aug. 6
0	12.8	13.3	12.8
40	8.7	8.5	7.1
100	7.7	7.2	4.5
150	6.8	6.0	5.1
190	6.0	8.3	----------

OFF THE NORTHEAST COAST OF MAINE

Depth, meters	1912 10033 Aug. 16	1913 10098 Aug. 13
0	10.6	10.3
20	10.1	9.6
40	9.7	9.3
60	9.6	9.1

NORTHEAST CORNER OF GULF

Depth, meters	1912, 10036	1913, 10097	1914, 10246
0	10.6	12.8	14.4
20	10.2	11.7	10.0
40	9.3	10.4	8.4
60	8.9	9.2	7.3
80	8.6	8.4	6.6
100	8.3	7.7	6.3
120	8.0	7.3	6.6
140	7.6	6.7	7.3
160	7.4	6.5	7.8
180	7.4	6.2	8.0
200	----------	6.0	[3]8.2

[3] At 190 meters.

"PRINCE" STATION 3

[In the center of the Bay of Fundy, between Grand Manan and Nova Scotia, from data by Craigie (1916a), Vachon (1918), and Mavor (1923).

Depth, meters	1914 Aug. 27	1916 Aug. 25	1918 Sept. 4	1919 Aug. 26
Surface	11.2	10.1	12.2	11.3
10	10.4	9.9	11.2	11.1
25	9.5	9.1	9.2±	9.1
50	9.2	7.4	7.7	7.9
75	9.2	6.5	6.7	7.4±
100	8.8	6.1	6.1	7.1
150	8.5	5.8	6.2	7.0
175	8.4	5.8	6.1	6.7

Annual differences in temperature—Continued

WEST SIDE OF EASTERN BASIN

Depth, meters	1912 10027 Aug. 14	1913 10092 Aug. 11	1914 10249 Aug. 12	1915 10309 Sept. 1
0	15.0	16.7	17.5	15.6
20	9.2	8.1	9.1	12.5
40	7.8	6.7	6.4	10.3
60	7.4	5.8	5.7	8.5
80	7.2	5.6	5.3	6.8
100	6.1	5.9	5.3	5.9
120	6.6	6.1	5.5	5.8
140	6.2	6.1	5.9	5.9
160	6.1	6.1	6.1	5.9
180	6.0	6.1	6.0	6.0
200	----------	6.1	5.9	6.1
220	----------	6.1	5.8	----------
240	----------	6.1	----------	----------

OFF LURCHER SHOAL

Depth, meters	1912 10031 Aug. 15	1913 10196 Aug. 12	1914 10245 Aug. 12	1915 10315 Sept. 7
0	13.3	12.1	14.4	12.2
25	11.8	10.5	10.3	11.3
50	10.7	9.4	9.2	10.1
75	10.1	8.6	8.8	9.9
100	8.5	7.4	8.6	----------

AUTUMNAL COOLING

SURFACE

The surface is at its warmest at some time during August in all those parts of the Gulf of Maine where the surface temperature rises much above that of the deep water in summer.[41] This includes the whole open area, except for the northeastern part, and the sites of active tidal mixing on the banks, the precise date of maximum surface temperature for any given summer depending on the prevailing weather. Our recent studies have not been sufficiently intensive precisely to locate this critical date for any one year or for any given locality in the gulf, but the records collected by Rathbun (1887) for the years 1881 to 1885 show that it may fall at any time between the first and last of August for the western and northern shores of the gulf between Nantucket Shoals and Penobscot Bay. After the first of September the surface of this subdivision cools as the autumn advances.

Experience in the summers of 1912, 1913, and 1914 suggests that the temperature of the upper layers of the western and deeper parts of the gulf generally (i. e., where vertical circulation is only moderately active) probably had passed its midsummer maximum, and that autumnal cooling had commenced there by the date of our late August and early September cruise of 1915. Thus, the highest reading recorded on August 31 and September 2 of that year, on the run eastward from Gloucester toward Cape Sable, was only 17.6°, contrasting with a probable maximum of about 19° to 20° over the western side of the basin during mid August. The seasonal schedule seems to have been about the same in 1925, also, when the *Halcyon* had surface readings of 16.6° a few miles north of Cape Ann, 15.2° on Platts Bank, and 14.7 between the latter and Portland on September 3.

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[41] The temperature of inclosed harbors is highest in July, mirroring the summer maximum for the air (p. 585).

The more tide-swept waters along and among the islands east of Casco Bay where the whole column of water continues nearly homogeneous in temperature through the summer and the surface warms only to about 11° to 13° instead of 16° to 18°, do not commence to chill until a month or more later in the season. In 1925, for example, the surface temperature near the Duck Islands, off Mount Desert, was almost exactly the same on September 9 and 10 (11.1° and 10.8°) as it had been there on August 11 (10.9°), 10° on September 15, and still 10.3° to 10.8°, on October 15 to 16. Readings of 10.28° off Machias and of 11.6° near Mount Desert on September 15 and 16, 1915, are in line with this.

This same rule holds good for the Bay of Fundy, where no appreciable cooling takes place until after the first of October—a month later than in Massachusetts Bay or off Cape Ann. Thus, Vachon (1918) had surface readings of 9.21° to 11.07° in the central parts of the bay on September 27 and October 4, 1916, with 9° to 10.6° at various localities in Passamaquoddy Bay between October 3 and 17, showing a cooling of only about 1° to 2° from the summer maximum. Mavor (1923) likewise records surface temperatures of 11.07° between Grand Manan and the Nova Scotian shore on October 4, 1916, and 9.77° on October 2, 1918. However, the 10-day averages for Lubec Narrows (fig. 31) show that considerable variation is to be expected from year to year in the date after which the surface of this part of the coast water commences to chill, for a steady though slight cooling was recorded through September, 1920, whereas the mean surface temperature at Eastport averaged highest at the last week of September for the 10-year period, 1878 to 1887.

Surface readings of 9.4° on German Bank (station 10311) and 13.3° near Cape Sable (station 10312) on September 2, 1915, suggest that the temperature was then about stationary at its summer maximum in this side of the gulf.

With the surface along the western shores of the gulf, from Massachusetts Bay northward, chilling rapidly during the early autumn, but with the northeastern and eastern margin of the gulf cooling only very slowly at first, there comes a time when the whole peripheral belt of the gulf outside of the outer headlands is nearly uniform in surface temperature (close to 9.5° to 10.5° in most years), varying only a couple of degrees, at most, from place to place. In 1915 this state was apparently attained sometime between the first and middle of October, the surface of Massachusetts Bay having chilled to 10.5°–13.4° by the last week of September (stations 10320 to 10324), with 11.6° off the Isles of Shoals and 11.9° off Cape Elizabeth on October 4 (stations 10325 and 10326), 10° at the mouth of Penobscot Bay (station 10329), and 9.4° near Mount Desert and off Machias on the 9th (stations 10327 and 10328). The surface of Massachusetts Bay continued virtually constant at about 11° throughout October.

The following tabulation (p. 638) of Rathbun's (1887) graphs for the years 1881 to 1885 likewise shows extremely uniform averages of 11.67° to 9.44° on October 1 for Boon Island, Seguin Island, Matinicus Rock, Mount Desert Rock, and Petit Manan Island, localities where the midsummer temperatures for the same years would show a range of at least 6°.[42]

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[42] The average surface temperature at Thatchers Island, at the tip of Cape Ann, was somewhat higher (14.17°) for the two years, 1881 and 1882, at the beginning of October.

Unfortunately, it is not known whether autumnal cooling proceeds at as rapid a rate during October out over the basin of the gulf in general as it does along the western shore, nor are data available for Georges or Browns banks during that month; but Rathbun's (1887) tabulations show the surface almost as cool at Pollock Rip, off the southern angle of Cape Cod, on October 1 (11° to 13.5°) as it is in Massachusetts Bay at that same date. This applies also to the whole region of Nantucket Shoals, where the *Halcyon* had surface temperatures of 11.6° to 12.2° on October 1, 1925, showing that a decided regional equalization had taken place since midsummer, when surface readings in the same region have ranged from 11.6° to 16.4° (p. 1012).

The autumnal cycle of temperature to the southward of Marthas Vineyard lags several weeks behind that of the waters to the north and east of Cape Cod. Thus, the surface was 13.3° to 14.4° across the whole breadth of the continental shelf off Marthas Vineyard on October 22, 1915 (stations 10331 to 10333), with 15.5° a few miles outside the continental edge, while the *Halcyon* had 13.3° near No Mans Land on the 28th of the month in 1925. This corresponds closely with Rathbun's averages of 15° for October 1 and 11.7° for November 1, 1881 to 1885, 22 miles off Nantucket (the old situation of Nantucket South Shoals lightship, which has since been relocated).

Average and extreme surface temperature, ° C., 1881 to 1885, from Rathbun's (1887) graphs, to the nearest half degree only

Date	22 miles SSE. of Nantucket, lat. 40° 54′, long. 69° 49′		Pollock Rip Lightship		Boon Island Light		Seguin Light		Matinicus Rock		Mount Desert Rock		Petit Manan Island[1]	
	Av.	Ex.	Av.	Ex.	Av.	Ex.	Av.	Ex.	Av.	Ex.	Av.	Ex.	Av.	Ex.
Oct. 1	15.0	14.5–15.5	13.0	11.0–13.5	11.0	9.5–12.0	11.0	9.5–12.0	10.5	10.0–11.5	9.5	9.0–10.5	11.5	11.0–12.0
Nov. 1	11.5	11.0–12.0	10.0	9.5–10.5	9.0	7.0–10.5	9.0	8.0–9.5	9.5	8.5–10.0	8.5	8.0–9.5	9.5	9.5
Dec. 1	7.5	6.5–8.5	6.5	4.5–8.5	[2]6.0	5.5–6.0	5.5	5.0–6.25	7.0	6.0–8.5	5.5	2.0–7.0	6.5	5.5–8.0
Dec. 16	6.0	5.0–6.5	5.5	3.5–6.5	5.0	4.0–6.0	4.0	3.0–5.0	5.5	4.5–6.5	5.0	3.0–6.5	4.5	3.0–6.0

[1] For years 1884 and 1885 only, the readings for 1881 and 1882 being omitted because so irregular that their reliability is doubtful.

[2] Omitting one reading of 0.56°, which was obviously an error.

SUBSURFACE

At first the autumnal cooling of the surface, which accompanies the cooling of the air, is due not only to an actual loss of heat by radiation (p. 692) but reflects mixture with the cooler underlying water, a process that correspondingly warms the latter. The result is that the annual maximum is attained later and later in the year as the depth of observation increases down to about 100 to 150 meters, or to the lower boundary of the stratum, the temperature of which is controlled by solar warming alternating with winter chilling. Consequently the wide vertical range of temperature that characterizes most parts of the gulf in summer gradually gives place to a state of vertical homogeneity as the autumn progresses. In 1915 (a typical year) autumnal cooling had affected only the uppermost stratum of Massachusetts Bay up to the end of September, the 20 to 25 meter temperature having continued virtually stationary at the midsummer value (11° to 12°) up to that date, with a rise of 2° to 3° at greater depths, resulting, no doubt, from the constant tendency toward vertical equalization by tidal mixing.

The profile for this date (fig. 69) shows that cooling had proceeded less rapidly in the southern side of the bay next to Cape Cod, which receives warm water from Cape Cod Bay, than in the central and northern parts, making the regional variation wider than it is in summer (fig. 66). Temperature of the upper 40 meters of Massachusetts Bay, however, was virtually equalized at 9.5° to 11.5° by the last week of that October (stations 10237 to 10239). On the other hand, vertical stirring had been active enough to raise the temperature of the 80 to 150 meter stratum of the bowl off Cape Ann from 5.8° on August 31, 1915, to 6.8° to 7° on October 1 (stations 10306 and 10324).

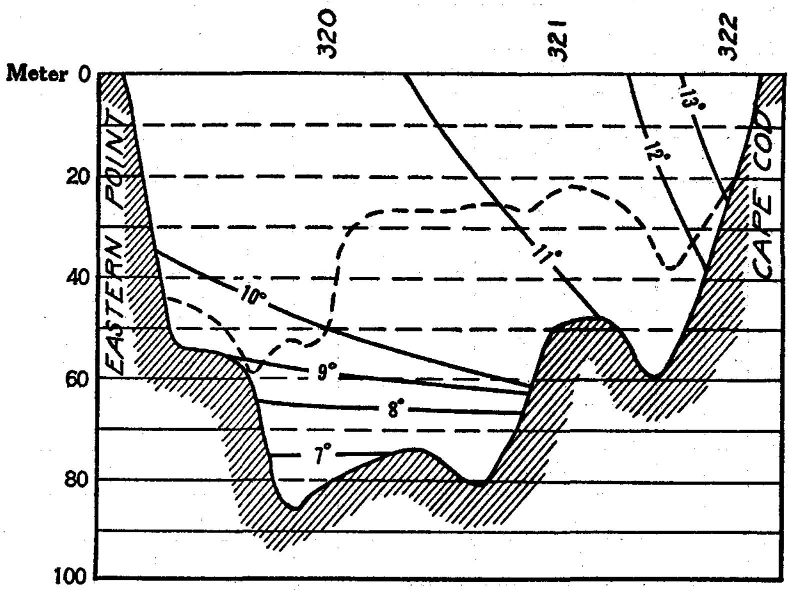

FIG. 69.—Temperature profile at the mouth of Massachusetts Bay, inside Stellwagen Bank, September 29 to October 1, 1915 (stations 10320 to 10322). The broken curve shows the contour of the bank

The thermal cycle was essentially similar in the cold year of 1916, when the 80 to 90 meter level was nearly 2° warmer at the mouth of the bay on October 31 (station 10399, 5.43° at 90 meters) than it had been on July 19 (station 10341, 3.67° at 80 meters), although the surface had cooled from 16.4° to 10° during the same interval, or to about the temperature normal for the outer part of the bay at that season.

Graphs for temperature off the Isles of Shoals and off Cape Elizabeth on October 4, 1915 (stations 10225 and 10226), and at various dates in August (fig. 70.) show much the same seasonal change as Massachusetts Bay, characterized by considerable cooling at the surface, but at a decreasing rate, down to about 30 to 40 meters, contrasted with a slight warming at greater depths down to bottom in 145 to 175 meters. However, it is impossible to state the precise rate of change for any given level for any one year from the data at hand.

The entire column of water down to 30 meters had cooled to about 10° at the mouth of Penobscot Bay by October 9, 1915, with about 9° at 60 meters, corresponding to a decrease of 3° at the surface, but a rise of about 1° at depths greater than 20 to 25 meters (fig. 71).

The surface (9.4°) was about 0.7° colder than the bottom near Mount Desert Island in 60 meters depth (10.1°) on October 9, 1915 (station 10328), the bottom having warmed since August about as rapidly as the surface had cooled. Probably the temperature would have been found homogeneous there from surface to bottom at about 9.5° a week or so earlier in the season, as it was off Machias, Me., on that same date (station 10327), with a reading of 9.4° at the surface and 9.83° close in to the bottom.

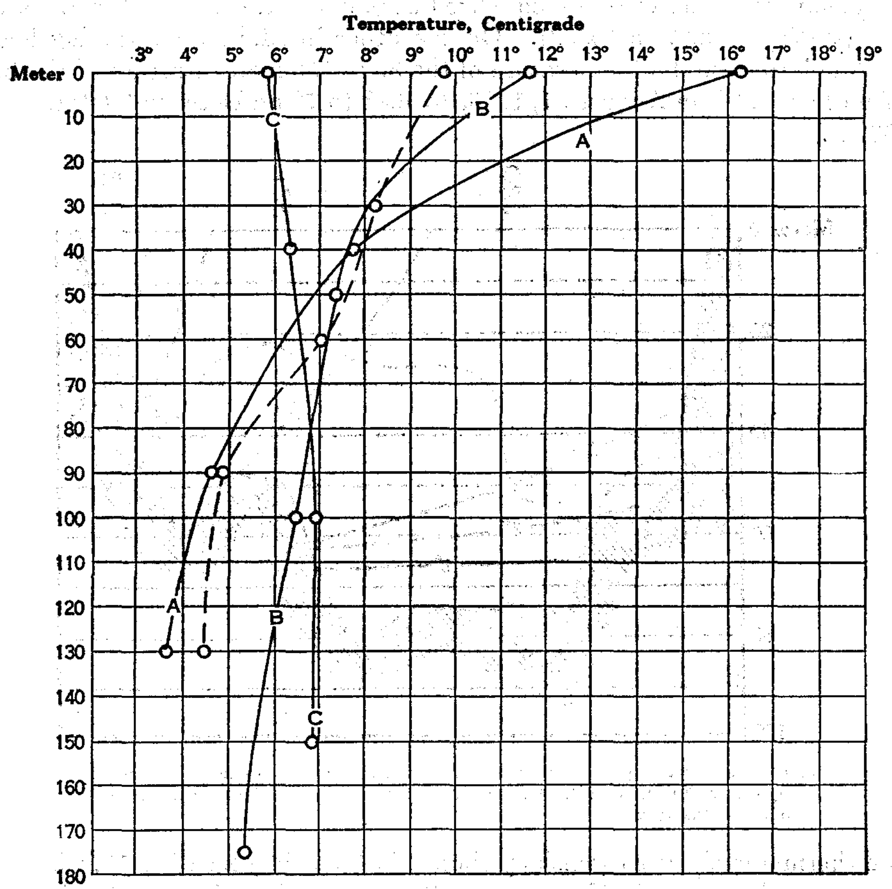

FIG. 70.—Vertical distribution of temperature in the trough between the Isles of Shoals and Jeffreys Ledge, to show the progress of autumnal cooling. A, August 15, 1914 (station 10252); B, October 4, 1915 (station 10325); C, December 30, 1920 (station 10493). The broken curve is for November 1 of the cold year 1916 (station 10400)

The whole column of water warms slowly in the deeper parts of the Bay of Fundy throughout the summer, and at a more nearly uniform rate vertically than is the case in the deeps of the open gulf. Probably this process continues into September every year, sometimes into October, as happened in 1916 (Vachon, 1918, tables, p. 309), with the bottom water continuing to warm for some time after the surface has commenced to cool. Judging from Mavor's (1923) tables, the depths greater than about 60 meters in the trough between Grand Manan and the Nova Scotian shore of the bay may be expected to warm by about 1° after the date when the surface reading is highest and before the deep layers also commence to show the chilling effect of autumn. In 1917 the temperature of the mid-stratum rose from about 6° to 7° there on September 4 to 7°–8° on October 2, but the maximum (6° to 7°) was not attained at depths greater than 60 meters until some weeks later in 1916.

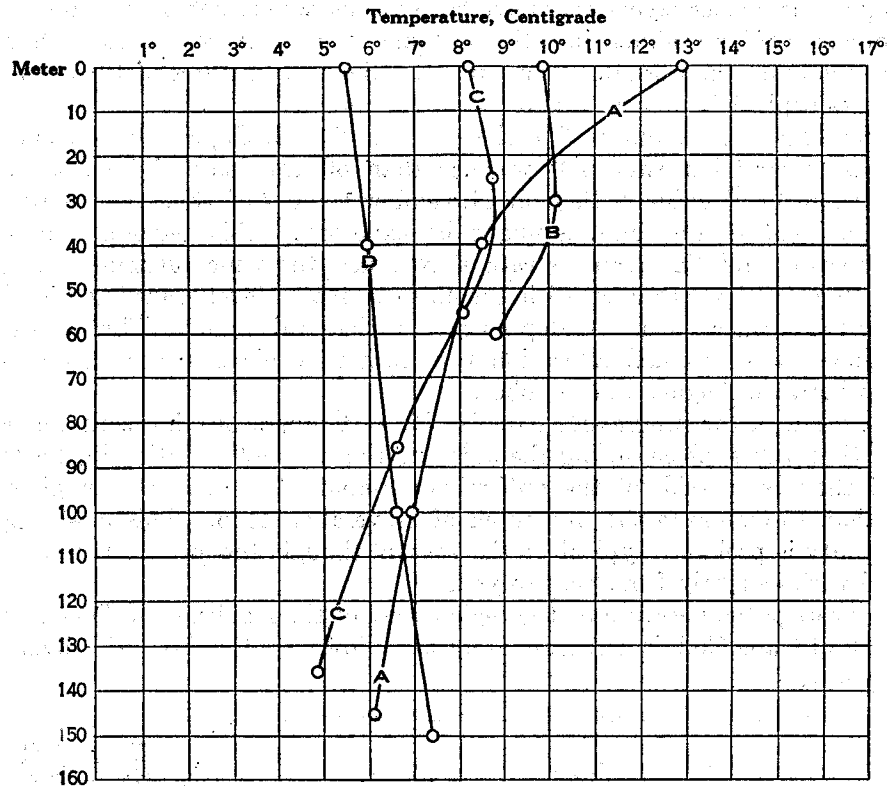

FIG 71.—Vertical distribution of temperature off Penobscot Bay at successive dates, to show the progress of autumnal cooling. A, August 14, 1914 (station 10250); B, October 9, 1915 (station 10329); C, November 2, 1916 (station 10402); D, January 1, 1921 (station 10496)

In the lower part of Passamaquoddy Bay, Vachon (1918; *Prince* station 4) found the whole column in 30 meters depth cooling after October 3 as follows:

Depth	Oct. 3, 1916[1]	Oct. 16, 1916[1]	Oct. 21, 1916[1]	Oct. 27, 1916[1]
	°C.	°C.	°C.	°C.
Surface	10.60	9.35	9.32	8.51
20 meters	9.83	9.14	9.08	8.81
30 meters	9.82	8.98	[2]8.88	8.80

[1] From Vachon's (1918) tables.

[2] 26 meters.

In 1916 the temperature of the upper 30 meters was about the same a few miles off Cape Ann on October 31 (station 10399, surface 10°, 30 meters 9.18°) as it was on the 3d to the 16th in Passamaquoddy Bay, showing a regional difference of about two weeks in the autumnal schedule between the southwestern and the northeastern parts of the gulf. This corresponds both to the land climate and to the difference in latitude.

Our only records of autumnal temperatures for the offshore parts of the gulf later than the first week of September are for its western and southwestern parts, where serial readings were taken on November 1, 1916 (station 10401), and again on the 8th of the month (station 10404). In this very cold year the autumnal warming of the deeper layers may have lagged some weeks behind the normal; the inflow of water of high salinity into the bottom of the trough seems also to have been in smaller volume than usual. Consequently, the temperatures of 1916 can hardly be taken as typical for depths greater than 100 meters.

Surface readings about 0.5° higher in the offing of Cape Ann (station 10401, 10.6°) than near Gloucester, 0.9° warmer than off the Isles of Shoals, and 1.3° warmer than off Penobscot Bay on November 1 and 2 of that year show cooling most rapid next to the land, as might be expected. This regional difference is slight, however, and the deeper strata show much the same autumnal change offshore as they do closer to land, with the 40 to 70 meter level warming slightly (fig. 72) while the surface cools. At depths greater than this annual differences entirely overshadowed any seasonal alteration that may take place in the western side of the basin between August and October.

As a result of the progressive equalization of temperature, horizontal as well as vertical, that takes place during the autumn, the regional variation in the temperature of the western side of the gulf was only about 1.5° to 2° at any given level deeper than 15 meters in the first week of November, 1916. This close approach to uniformity is probably typical of the season, though the precise temperature at any level varies slightly from year to year.

The average temperature of the region west of the longitude of Penobscot Bay and north of Cape Cod is approximately as follows by the first of November in normal years:

Depth	Average temperature Aug. 15	Average temperature Nov. 1	Seasonal change
	°C.	°C.	°C.
Surface	15.0-18.0	10.0	−5.0-8.0
20 meters	11.5	9.5	−2.0
40 meters	7.2	8.9	+1.6
70 meters	5.6	7.0	+1.4
100 meters	4.7	5.0	+.3

No records of the subsurface temperatures have been taken on Georges Bank in autumn. In the shallow water of Nantucket Shoals autumnal cooling may at first reduce the temperature of the surface slightly below that of the bottom, the *Halcyon* having recorded surface readings of 11.6° to 12.2° on October 1, 1925, on the shoal, when the bottom water was 12° to 13.5° in a depth of about 25 meters (p. 1013).

The whole column, however, cools nearly uniformly on the shoals during October, whether the surface be slightly cooler than the bottom or slightly warmer at this season depending on the wind as the latter moves the surface water in or offshore.

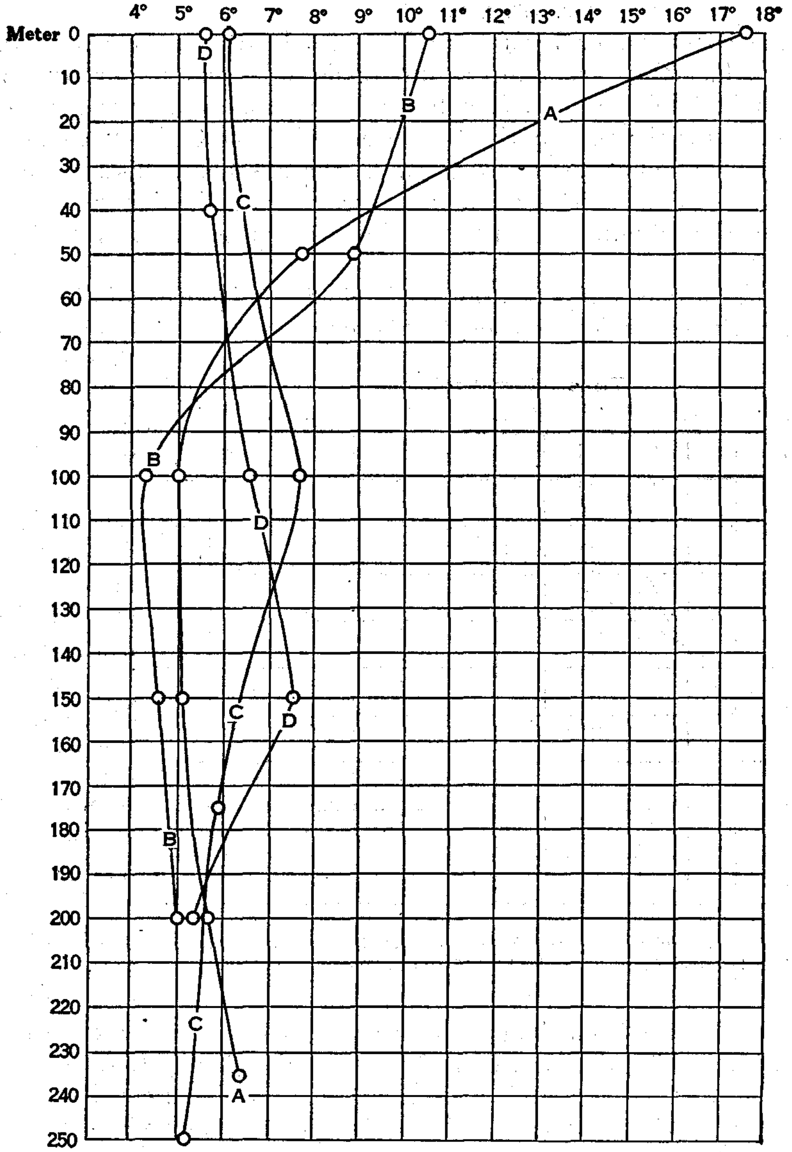

FIG. 72.—Vertical distribution of temperature in the western arm of the basin of the gulf in autumn and winter. A, August 31, 1915 (station 10307); B, November 1, 1916 (station 10401); C, December 29, 1920 (station 10490); D, January 9, 1921 (station 10503)

The upper 40 meters of water over the continental shelf, south of Marthas Vineyard and out to the edge of the continent, was vertically homogeneous in temperature at 13° to 14.5° by October 22, 1915 (stations 10331 to 10333, fig. 73).

We again found the superficial stratum over this part of the shelf equally homogeneous in temperature in November, 1916. While the bottom water then showed slight vertical cooling at depths greater than 30 to 40 meters, it was considerably warmer then than it had been there in August—a state obtaining as far southward as Chesapeake Bay (Bigelow, 1922, p. 123).

Thus, the coast water off southern New England corresponds to the Gulf of Maine in the fact that the temperature tends to become uniformly homogeneous during September and October, though the change takes place at a temperature 3° to 4° higher than is the case to the northward of Cape Cod. "A seasonal change of this sort was, of course, to be expected in the absence of disturbances by extralimital currents, as the first step in the vertical equalization of temperature so characteristic of northern coastal waters in late autumn and winter." (Bigelow, 1922, p. 123.)

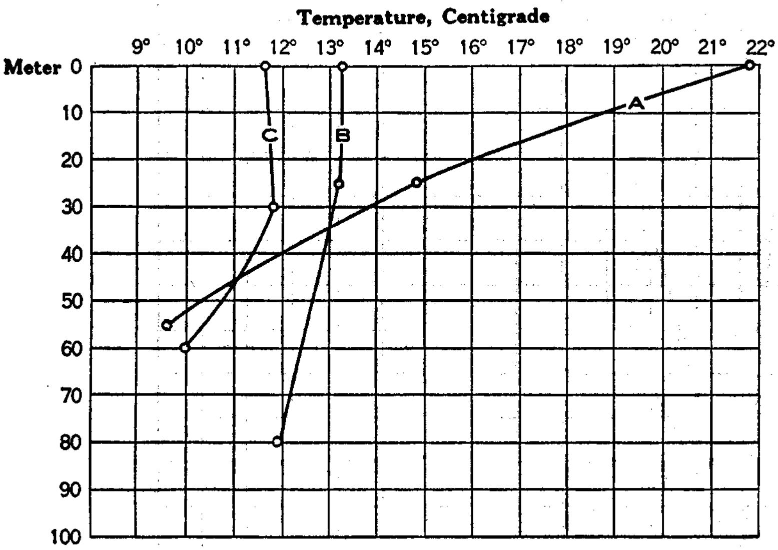

FIG. 73.—Vertical distribution of temperature off Marthas Vineyard to show autumnal cooling. A, August 25, 1914 (station 10259); B, October 22, 1915 (station 10333); C, November 1, 1916 (station 10406)

In 1916 the surface temperature near land a few miles west of Marthas Vineyard had fallen fractionally below that of the 30-meter level by November 10 to 11 (stations 10405 to 10408); and although this profile lies a few miles west of the geographic limits covered by this report, it is reproduced here (fig. 74) because the readings would have been nearly the same had it been run out from Marthas Vineyard on the same date. Its most instructive feature is its demonstration of the fact, now sufficiently established, that autumnal cooling in the coastal waters off the northeastern United States proceeds from the land seaward. In 1916, as I have earlier remarked (Bigelow, 1922, p. 123), this process had progressed so far by that date as to nearly obliterate the preexisting stability of the water on the inner half of the shelf. Farther offshore, however, where the immediate surface alone had yet been chilled by the cool land winds, the underlying water at 20 to 50 meters still continued 1° to 2° warmer than the superficial stratum above or the bottom water below. As a result the curves for 12° and 13° might suggest a landward intrusion of water from offshore if taken by themselves. However, the salinities forbid this interpretation, proving this apparent tongue merely reminiscent of the maximum temperature to which this level had warmed during the preceding summer (Bigelow, 1922, p. 123).

A thermal distribution of the opposite sort, with a shelf of cold water projecting seaward, has been recorded repeatedly off this part of the slope at the end of the summer.

NOVEMBER AND DECEMBER

In 1912 the whole column of water off Gloucester had become vertically homogeneous in temperature (about 9°) by November 20 (fig. 75), suggesting that autumnal cooling had proceeded at about the same rate there as it did in 1915 and 1916 (p. 638), while the whole column, 70 meters deep, had cooled to about 7.8° to 8.1° by December 4 (station 10048). It is interesting that the immediate surface was 0.1° to 0.3° warmer there than the deeper levels on both these dates, which may have reflected irregularities and setbacks in the progress of cooling from day to day, because both these stations were occupied after one or two warm days, though on both occasions the air temperature was a degree or so colder than the water at the times the readings were taken.

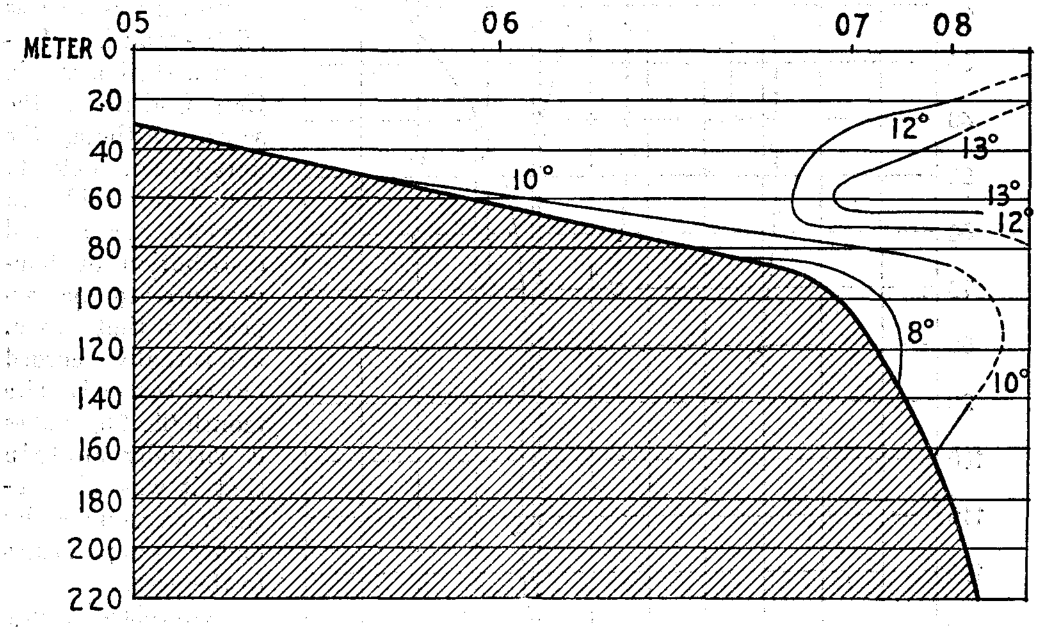

FIG. 74.—Temperature profile crossing the continental shelf off Narragansett Bay, November 10 and 11, 1916 (stations 10405 to 10508)

The *Fish Hawk* again found the temperature virtually uniform vertically, from surface to bottom, all along the southern side of Massachusetts Bay on Decmber 3, 1925, in depths of 25 to 40 meters; in fact, the surface reading did not differ by more than 0.2° from the intermediate or bottom reading at any of the 10 stations. The progress of autumnal cooling also was made evident by a mean temperature of about 6.2° for this side of the bay. Although the preceding autumn had been unusually mild (suggesting that in most years the sea temperature is a degree or two lower by that date), one station off Plymouth Harbor (No. 10) and two at the head of the bay (Nos. 16 and 17) were then fractionally cooler at the surface than deeper—evidence that the water had been rapidly losing heat from the surface for some days previous, which can be associated with a cold northwest gale on November 23. No great horizontal variation in temperature was to be expected over so small an area; in fact, all the readings for this cruise fell within the limits of 4.80° and 6.93°.

The slight differences recorded from station to station on this cruise prove unexpectedly instructive, because the coldest water (4.8° to 5.8°) then formed a more or less definite pool close inshore, a few miles north of Plymouth, with appreciably higher temperatures (6.8° to 6.9°) to the northward as well as off the mouth of Plymouth Harbor and in Cape Cod Bay to the south. Although the data do not suffice to bound this cold area offshore, the general distribution of temperature to be expected at that season, and actually recorded there later in the month (fig. 76), makes it virtually certain that it was also entirely surrounded by higher temperatures to the east.

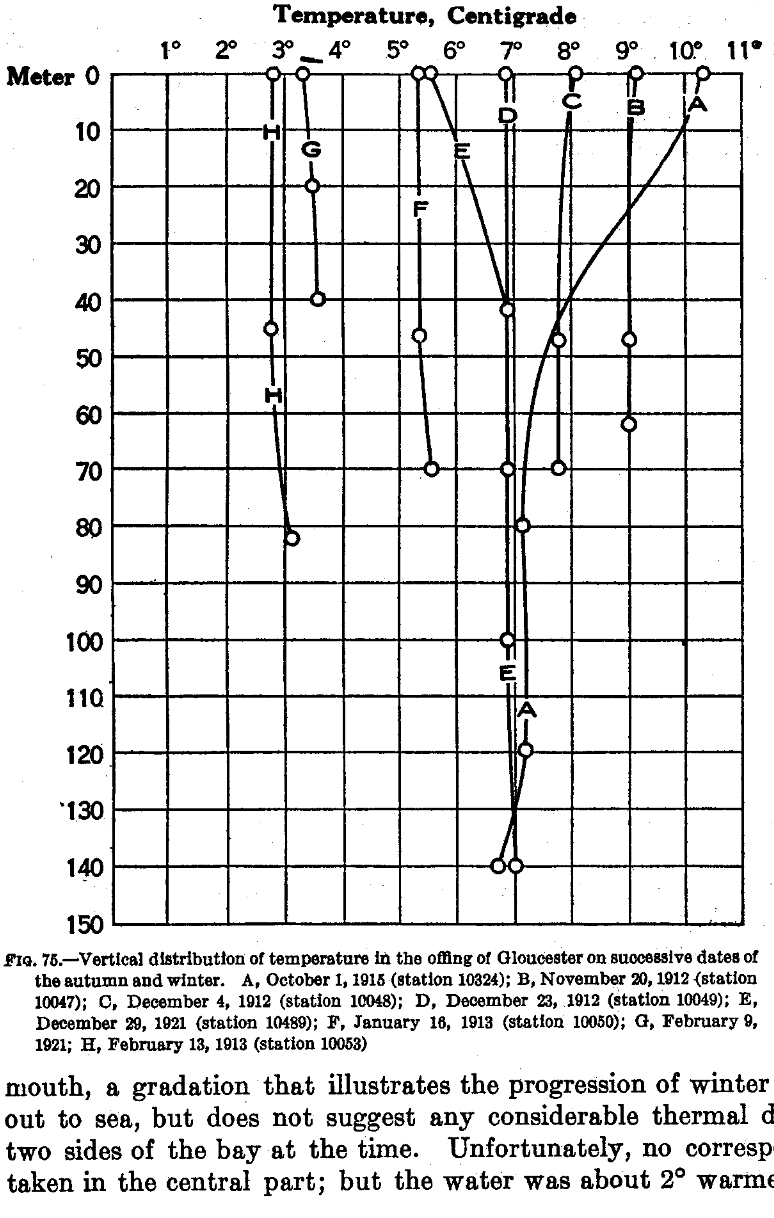

FIG. 75.—Vertical distribution of temperature in the offing of Gloucester on successive dates of the autumn and winter. A, October 1, 1915 (station 10324); B, November 20, 1912 (station 10047); C, December 4, 1912 (station 10048); D, December 23, 1912 (station 10049); E, December 29, 1921 (station 10489); F, January 16, 1913 (station 10050); G, February 9, 1921; H, February 13, 1913 (station 10053)

On this same day (December 3), C. G. Corliss, superintendent of the Gloucester hatchery, found the surface water 4.4° in Gloucester Harbor and 5.6° at a locality 1 to 2 miles off its mouth, a gradation that illustrates the progression of winter cooling from the land out to sea, but does not suggest any considerable thermal difference between the two sides of the bay at the time. Unfortunately, no corresponding readings were taken in the central part; but the water was about 2° warmer 7 miles off Gloucester on December 4, 1913[43] (also a mild year), than in the coastal belt on that same day in 1923. Temperatures of about 5° to 7° may therefore be expected around the shores of Massachusetts Bay, with about 8° in its center, by the first week in December in average years, with the water virtually homogeneous from surface to bottom.

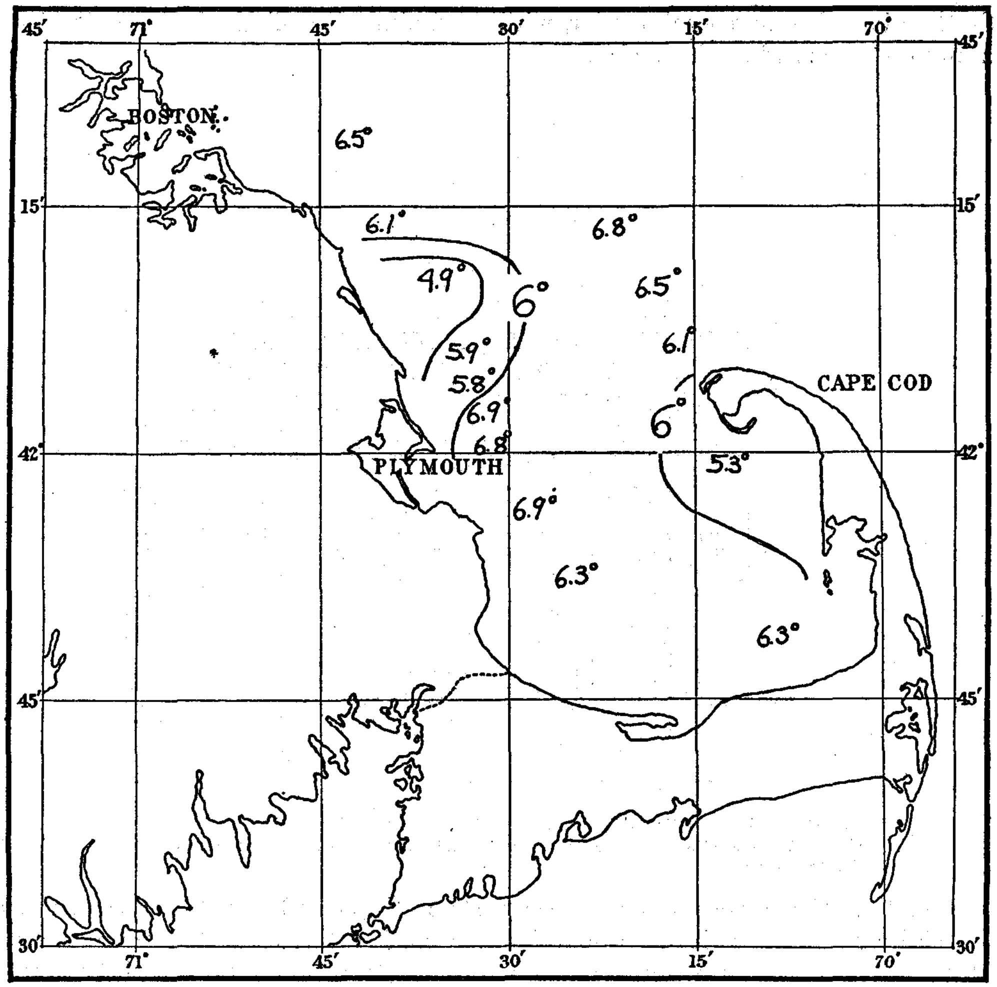

FIG. 76.—Surface temperature of Massachusetts Bay, December 9 to 11, 1924

The data for the *Fish Hawk* stations show that almost no change took place either in the actual temperature of Massachusetts Bay or in its vertical distribution during the first two weeks of December, 1925, the readings being fractionally higher for the second cruise than for the first at some stations, lower at others. The regional distribution remained unaltered, with the coldest water (5° to 6°) taking

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[43] Station 10048; 8.1° at the surface, 7.8° at 46 meters and 70 meters.

the form of an isolated pool near the western shore, surrounded by slightly higher temperatures (fig. 76). Equally cold water (about 5.3°, surface to bottom) off the mouth of Provincetown Harbor (station 5) now marked the shallows of the latter as a second center for local cooling.

After cold west winds on December 13, 14, and 15, the whole column of water averaged about 1 degree colder in the southern half of the bay on the 16th and 17th than it had been a week earlier, with a maximum cooling of about 2° and a minimum of about 1° at the surface.

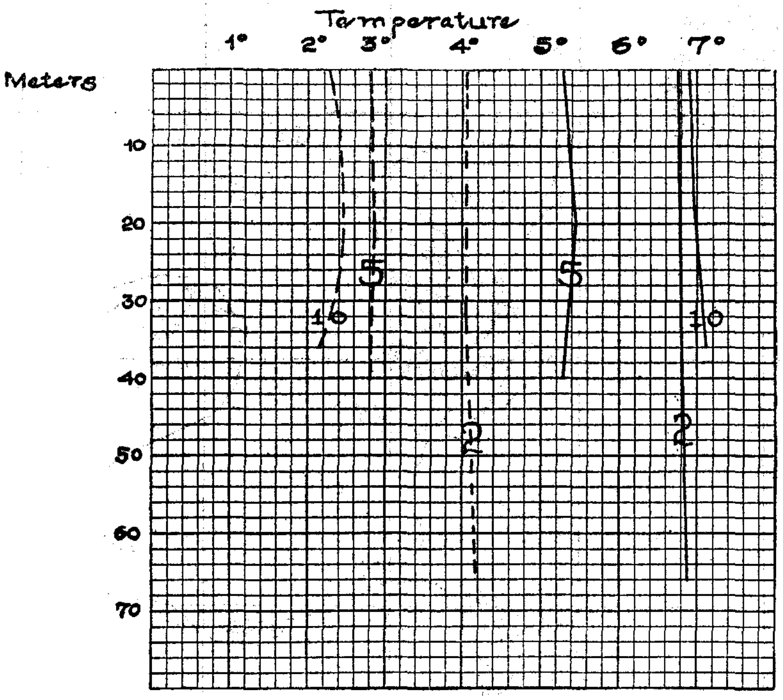

Fig. 77.—Vertical distribution of temperature at three representative stations in the southern side of Massachusetts Bay on December 9 to 11, 1924 (solid curves), and January 6 and 7, 1925 (broken curves).

Meantime the eastern and southern parts of Cape Cod Bay (5° at the surface) had definitely become a site of production for cold water, separated from the still colder pool next the land north of Plymouth (3.8° to 4.5°) by a slightly warmer wedge (5° to 6°) in the center of the bay. At this season the water of the bay is so nearly homogeneous, surface to bottom (fig 77), that a chart of the minimum temperature, irrespective of depth (fig. 78), illustrates this regional distribution better than a surface chart can.

When the temperature varies more widely between stations a few miles apart than between surface and bottom at any one station, as is the case in the southern

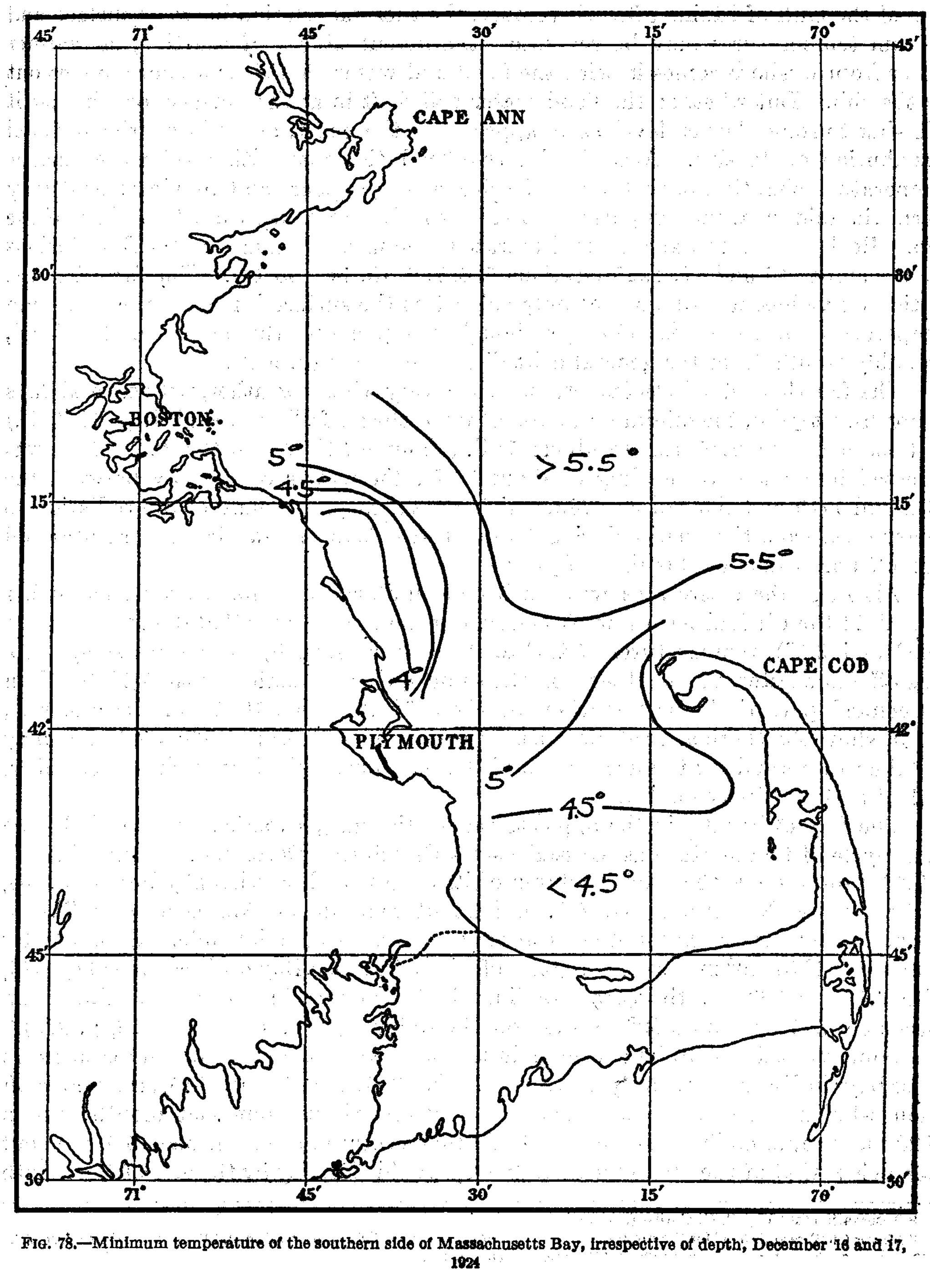

FIG. 78.—Minimum temperature of the southern side of Massachusetts Bay, irrespective of depth, December 16 and 17, 1924

side of the Gulf of Maine after November, the thermal relation between surface and bottom temperatures may be reversed at different stages of the tide, as warmer water from offshore comes in with the flood and water chilled near shore moves out on the ebb. But whether the flood water will drift in at the surface, or whether it will sink to some deeper level as it approaches the coast, depends on the regional distribution of density. Accordingly, the flood tide may either raise the surface temperature slightly above that of the deeper water near land in winter or it may warm the mid stratum temporarily, a state which may persist until the last of the ebb. Both these alternatives are illustrated among the Massachusetts Bay stations for December 16 and 17, 1925 (stations 5, 6, 7, 9, 13, 14, and 17). The fact that the station off Cohasset (16) was not only coldest at the surface but gave the minimum temperature for the cruise (3.8°), although taken about the middle of the flood, probably results from the general drift discussed below (p. 972).

The fourth week of December, 1925, saw very wintry weather, with several days of northwest gales, the minimum temperature of the air falling to −1° F. (−18.3° C.) at Boston on the 21st and to about 5° F. (about −15° C.) on the 22d. This was reflected by an average cooling of about 1° for the waters of the bay between the 16th and 17th and the 22d and 23d, which gives a rough measure of the radiation to be expected from the surface during two or three days of low air temperatures and high offshore winds at this time of year.

Although the entire area was much more uniform in temperature on December 22 and 23 than it had been a week earlier (all the readings for that date fell between 4.95° and 2.5°), temperatures of 2.5° to 3° near Plymouth, in the one side, and a mile off Gloucester, in the other,[44] on the same day, contrasting with 4.5° to 5° in the central part of the bay (station 18; about 7° at station 10049 on December 23, 1913), show the thermal gradation usual for the winter season. Thus, 4° to 7° may be taken as normal for the deep parts of the bay during the last week in December, and 2° to 4° for its coastal belt.

The Bay of Fundy, in the opposite side of the gulf, experiences essentially the same cycle of temperature as Massachusetts Bay during December. Thus, Mavor's (1923) tables show the whole column of its deep trough as virtually homogeneous, vertically, by November (fig. 79), and about reproducing Massachusetts Bay in temperature in December, notwithstanding the difference in latitude. Compare, for instance, 6.4° to 6.9° in the central parts of Massachusetts Bay on December 11, 1925, with 6.18° to 6.6° for the corresponding depth column in the Bay of Fundy on December 2, 1915, and 5.62° to 6.12° on December 5, 1917 (Mavor, 1923, p. 375).[45]

Some variation is to be expected in the vertical distribution of temperature in these bays in December from year to year. In 1913, as noted (p. 645), the water off Gloucester was homogeneous, surface to bottom, throughout that month; but in 1920 more rapid chilling had lowered the temperature of the surface (5.56°) about 1.5° below that of the 40-meter level (6.94°) at this locality by the end of the month

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[44] Observation taken by C. G. Corliss (p. 513.)

[45] Mavor (1923) records 6.11° for the surface, 6.42° at 50 meters, and 6.6° at 175 meters on Dec. 2, 1916; 5.62° at the surface, 5.72° at 50 meters, 6.16° at 100 meters, and 6.18° at 175 meters on Dec. 5, 1917.

(station 10489), and the Bay of Fundy was also fractionally colder at the surface than a few meters down at this season in 1916 and 1917.

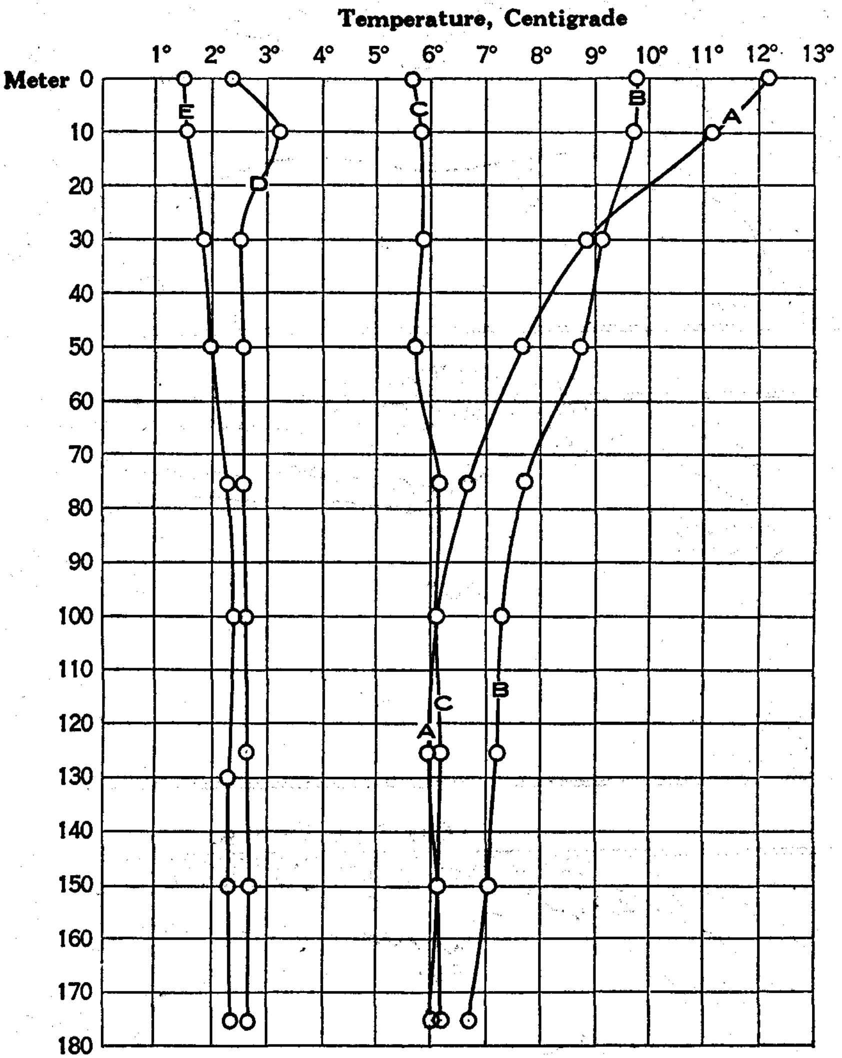
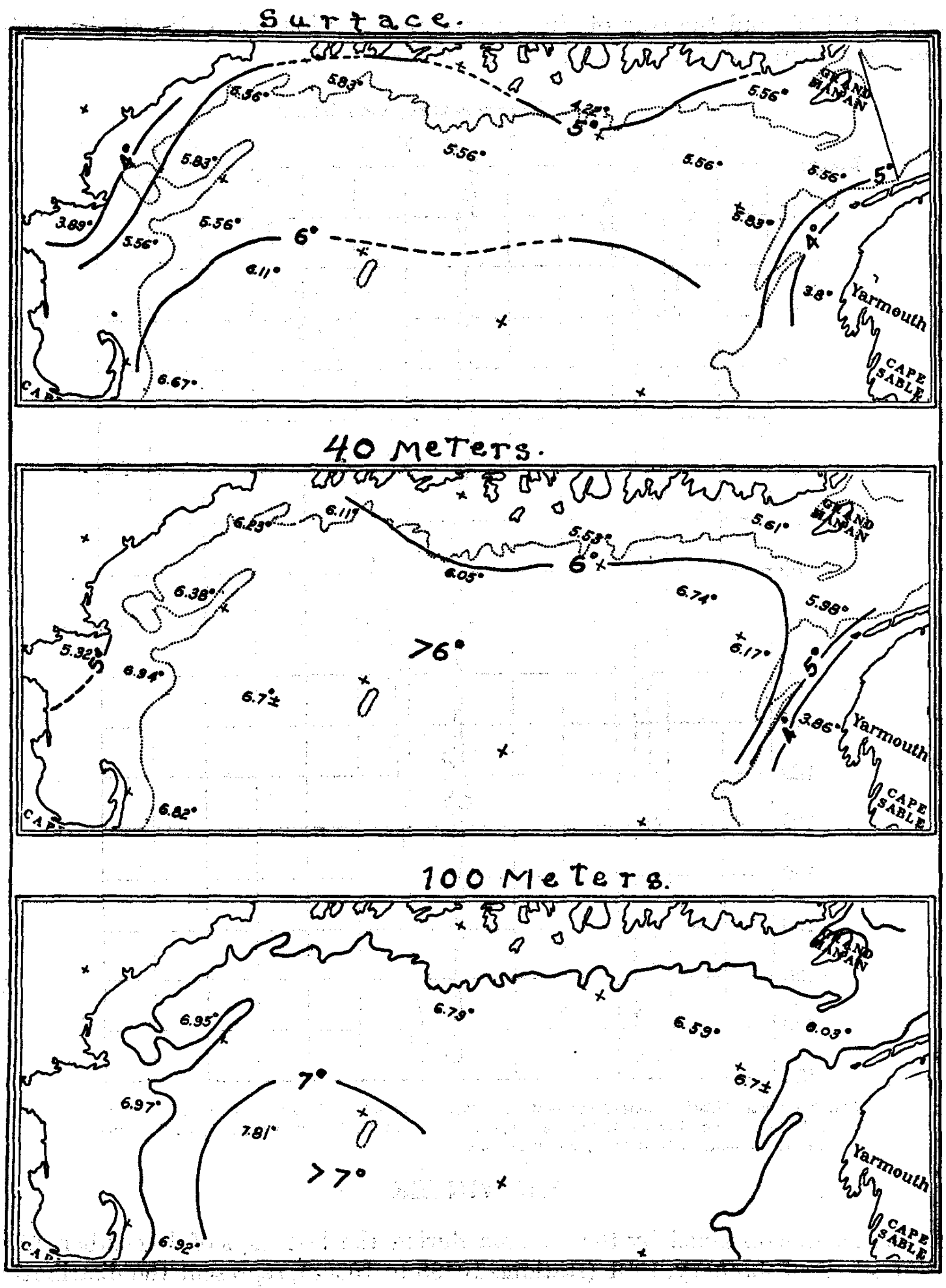


FIG. 79.—Vertical distributions of temperature at *Prince* station 3, in the Bay of Fundy, in autumn and winter, from Mavor's (1923) data. A, September 4, 1917; B, October 2, 1917; C, December 5, 1917; D, January 19, 1918; E, February 28, 1917.

MIDWINTER

The records obtained by the *Halcyon* during the last days of December, 1920, and first half of January, 1921 (stations 10488 to 10503), represent the distribution of temperature in the inner part of the open gulf for a midwinter neither unusually cold nor unusually mild.



Surface.

40 Meters.

100 Meters.

FIG. 80.—Temperature of the northern part of the gulf on the surface (upper chart), at 40 meters (middle chart), and at 100 meters (lower chart), December 29, 1920, to January 9, 1921

These several midwinter stations (fig. 80), combined, show that at this season any line run normal to the coast of the gulf would lead from lower surface temperatures out into slightly warmer water, with the surface then coldest (below 1°), locally, close in to the land between Boston and Cape Elizabeth on the one side of the gulf, and along Nova Scotia on the other; slightly warmer than 4° along the intervening coast sector, outside the outer islands, and about 6° on the central and southern parts of the basin (fig. 80); but the temperature may fall as low as 1° among the islands by the end of December, as happened at Boothbay and in Lubec Channel in 1919 (figs. 30 and 31).

These local differences result from the topography of the coast line, from the local winter climate, and from differences in the activity of vertical stirring by the tides. Thus, the surface chills more rapidly at the head of Massachusetts Bay than along the open coast of Maine because less actively mixed by the tides with warmer water from offshore and from deeper levels. Chilling takes place most rapidly of all in the sounds and harbors, because their enclosure prevents free interchange with the water outside.

In midwinter the surface is, as a whole, the coldest level, though differing by less than 1° from the warmest stratum at most of the stations. Thus, the inner part of Massachusetts Bay (station 10488) had cooled to 3.89° at the surface on December 29, with 5.86° on the bottom in 60 meters. In the bowl off Gloucester the readings were 5.56° at the surface and 6.9° to 7° from 40 meters down to the bottom in 150 meters, the latter almost precisely reproducing the temperature recorded there on December 23, 1912 (fig. 75). The surface was about 0.5° warmer 15 miles off the northern end of Cape Cod (station 10491), but the 100-meter level was about 0.1° cooler. The vertical distribution of temperature was the same near the land, off the mouth of the Merrimac River (station 10492), as near the head of Massachusetts Bay, and with the actual values nearly alike, while the trough off the Isles of Shoals (station 10493, fig. 70) agreed equally with the sink station off Gloucester just mentioned.

The vertical range of temperature was only about 0.2° off Seguin in about 80 meters depth on December 31, 1920 (station 10495, 5.83° on the surface, 6.1° at 40 meters, and 6.1° at 75 meters); but a few miles farther out from the influence of the land off the mouth of Penobscot Bay, the next day (station 10496), where the water is less subject to tidal stirring, the temperature curve closely paralled that for the Isle of Shoals station 2 days previous in the upper 100 meters (5.6° at the surface, 6.05° at 40 meters, and 6.79° at 100 meters), but showed a slight vertical warming at greater depths to 7.5° on the bottom in 150 meters. Surface (4.7°) and 90-meter readings (5.7°) differed by about this same amount close in to Mount Desert Island (station 10497). However, the temperature was uniform, surface to bottom, a few miles off Machias (station 10498, 5.56° to 5.61°), a state approximated here throughout the year.

In the Fundy deep the *Halcyon* found the whole column about 1° to 2° warmer on January 4, 1921 (station 10499), than Mavor (1923) records it for January 3, 1916; in fact, agreeing more closely with his temperatures for December 5, 1918, in spite of the difference in date, as follows:

Depth	Station 10499	Prince station 3, Jan. 3, 1917[1]
	°C.	°C.
Surface	5.56	3.69
50 meters	[2]6.00	4.56
100 meters	6.03	5.30
175 meters	[2]6.80	4.59

[1] From Mavor, 1923.

[2] Approximate.

Apparently the waters along the western shores of Nova Scotia are about as cold as the inner part of Massachusetts Bay in the first week in January, judging from 1921, when the temperature was uniformly 3.8° to 3.9°, surface to bottom, a few miles off Yarmouth (station 10501) on the 4th; or about the same at the surface as the reading off the mouth of Boston Harbor 5 days previous, with no wider difference at 20 to 40 meters than can be accounted for by more active vertical circulation and by this difference in date.

In the northeastern part of the trough, on January 5 (station 10502), the surface was coldest (5.56°) overlying a uniform stratum (6.6° to 6.7°) at 40 to 100 meters, with slightly warmer water (6.9° to 7.2°) at still greater depths; but readings taken in the western side of the basin for January 9 showed the water about 2° warmer at 100 to 150 meters than either the surface or the bottom (station 10503).

Thus, the level that is coldest in the western side of the basin in summer is warmest in midwinter—about 2.5° warmer, in fact (7.5° to 7.8°), than we have ever found it in August. A serial for late November is required for a correct picture of the autumnal change there; but the fact that the salinity of the 100-meter level was higher at this locality in December, 1920, than we have ever found it in August, September, or October (fig. 138), suggests that the temperature of its warm stratum had been maintained at about the November value (about 8°) throughout December by additions of warmer and more saline water from the southeastern part of the gulf, while the surface stratum had cooled. This reconstruction is corroborated, also, by the fact that while the surface continued to chill (about 0.5°) during the interval between December 29 (station 10490) and January 9 (station 10503), the 100-meter level warmed by about 0.5°, the 150-meter temperature rose by about 1.5° during the interval, with no corresponding increase in salinity (p. 994).

In horizontal projection the midwinter serials just discussed show the 40-meter level coldest (3.86°) in the eastern side of the gulf, off Yarmouth, Nova Scotia; 4° to 6° in Massachusetts Bay, along the coast of Maine east of Penobscot Bay, and at the mouth of the Bay of Fundy; 6° to 7° elsewhere (fig. 80). The temperature was regionally as uniform at 100 meters, also, varying only from 6.03° to 7.81° over the whole area—coldest in the mouth of the Bay of Fundy. At 200 meters, however, the regional distribution of temperature (also of salinity—p. 804), was just the reverse, being warmest (6.9° to 7°) in the northeastern branch of the basin and the Bay of Fundy and coldest in the western side of the basin off Cape Ann (5.3° to 5.6°).

No serial temperatures have been taken in the open basin of the gulf during the last half of January or the first three weeks of February, but records for the vicinity of Gloucester in 1913, for the southern side of the Massachusetts Bay region in 1925, and for the Bay of Fundy region show that the water continues to cool during these months. In 1924–25 cold weather at about Christmas was reflected in the southern half of Massachusetts Bay by temperatures about 2.5° lower on January 6 and 7 than they had been on December 22 and 23, the mean temperature having fallen to about 2.5° to 2.6°, surface to bottom.[46]

Large amounts of ice formed in the southeastern side of Cape Cod Bay during the low temperatures and northwest gales of the last week of that December, until it was packed several feet high on the flats and along the beaches south of Wellfleet, reaching for a mile or more offshore as I saw it on the 29th. Its chilling effect is reflected in the fact that the temperature of the water was much lower (0.3° on the surface, 0.25° on bottom in 13 meters) off Billingsgate Shoal on January 7 (*Fish Hawk* cruise 5, station 7) than at the other stations for that cruise.

The surface temperatures for this January cruise (fig. 81) are also instructive as an illustration of the gradation from lowest readings of 0.5° to 2.5°, close in to the shore, to warmer water (4° to 5°) in the center of the bay, characteristic of the season. A reading of 2.78° a mile off the mouth of Gloucester Harbor on this same date shows that the coldest band was continuous right around the coast line of the bay, as it had been the month before (p. 650).

Probably the mouth of the bay, generally, and the open basin in its offing are usually about 5° to 5.5° in temperature at the second week of January at all depths, judging from readings of 5.3° to 5.6°, surface to bottom, in 70 meters off Gloucester on the 16th of the month in 1913 (station 10050).

On January 6 and 7, 1925, the surface (fig. 81) was slightly cooler than the bottom at the four stations in the central part of Massachusetts Bay (*Fish Hawk* cruise 5, stations 19, 18, 2, and 4) and in the eastern side of Cape Cod Bay (station 6), fractionally warmer than the bottom in the southern part of the latter and along the Plymouth shore. Nor is the cause for this slight regional difference clear, for most of the stations of the second group, as well as of the first, were occupied on the ebb tide.

On January 9, 1920, Gloucester Harbor was between 0° and 1° (fig. 29), Boothbay Harbor fractionally colder than 0° (fig. 30), and Lubec Narrows about 0° (fig. 31), showing that the temperature falls about equally fast in such situations all around the western and northern shores of the gulf in spite of the difference in latitude.[47] The water is also about as cold at Woods Hole at this season (Sumner, Osburn, and Cole, 1913; Fish, 1925).

Massachusetts Bay is coldest during the first half of February; and this probably applies to the gulf as a whole. The precise date when the temperature fell to its minimum can not be stated for any of the years of record (no doubt this varies from year to year, as well as regionally), but the readings taken in the bay on February 6 and 7, 1925 (*Fish Hawk* cruise 6), were close to the coldest for that particular winter.

On this date the surface of the southern side of the bay (mean temperature about 0.75°) averaged about 2° colder than it had on January 6 and 7, though the regional distribution of temperature (fig. 82) continued reminiscent of the late December

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[46] The mean temperature of the air had been below normal at Boston on every day save three since Dec. 19.

[47] Gloucester Harbor, 42° 35′ N; Lubec Narrows, 44° 49′ N.

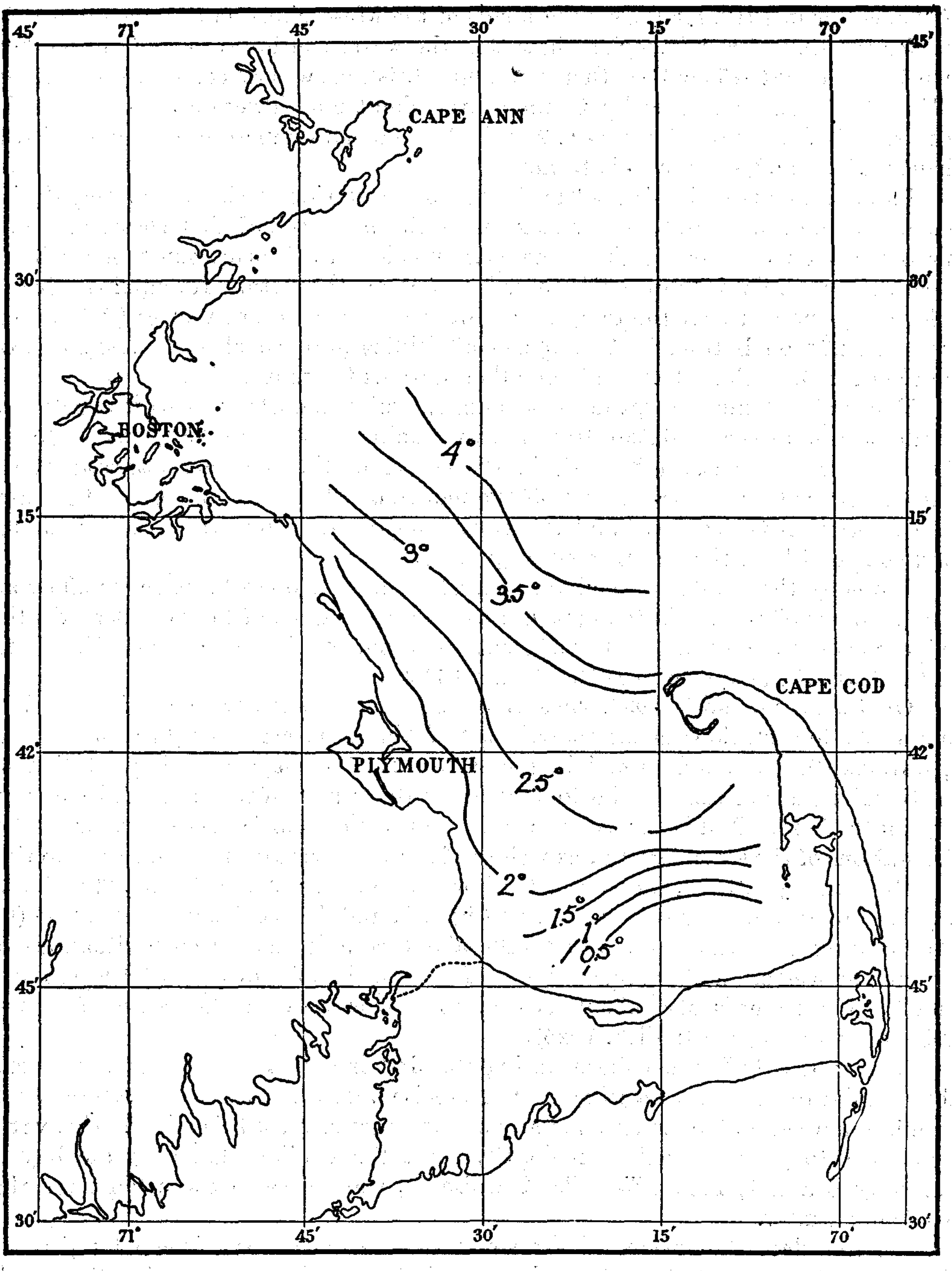

FIG. 81.—Surface temperature of the southern side of Massachusetts Bay, January 6 and 7, 1925

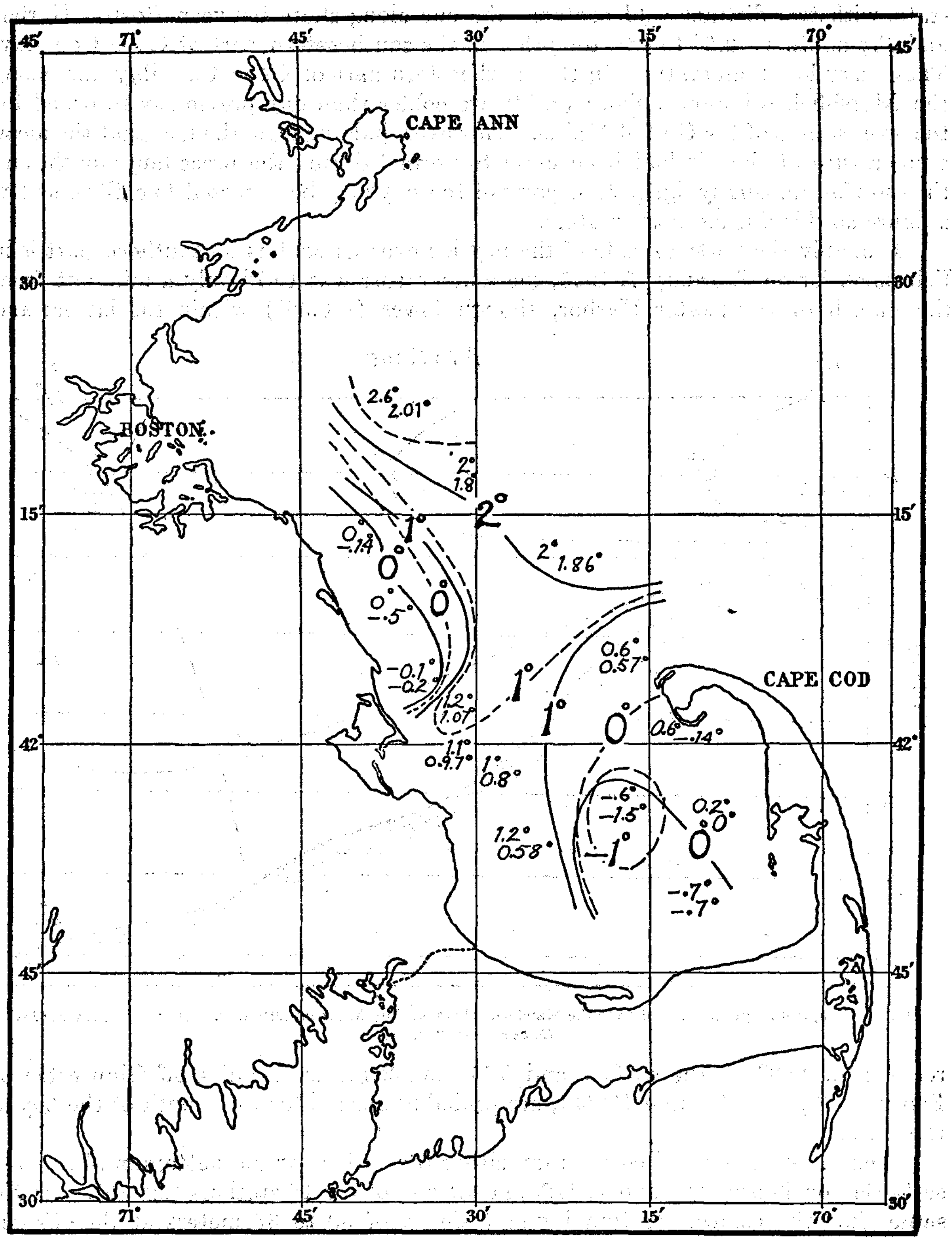

FIG. 82.—Surface temperature (solid curves) and minimum temperature (broken curves) of the southern side of Massachusetts Bay, February 6 and 7, 1925

state, with two distinct cold centers—the one along shore between Boston Harbor and Plymouth (−0.5° to 0°), the other in the southeastern part of Cape Cod Bay. These very low temperatures in the southeastern part of Cape Cod Bay and along the Marshfield-Plymouth shore (<0°) are colder than any previously recorded for the open waters of the Gulf of Maine. However, judging from the fact that the mean temperature of the air had been close to normal during the preceding month, and the snowfall unusually light, these parts of the bay may be expected to chill to as low a figure as this during most winters.

Probably the northern side of the bay is never as cold as its southern part is in February, for on February 7, 1925, the temperature was 1.67° only a mile out from the mouth of Gloucester Harbor, though lower (−0.56°) within the latter; and readings of 2.83° on the surface and 3.11° at 82 meters 7 miles off Gloucester on February 13, 1913 (station 10053), are probably normal for the mouth of the bay at this date.

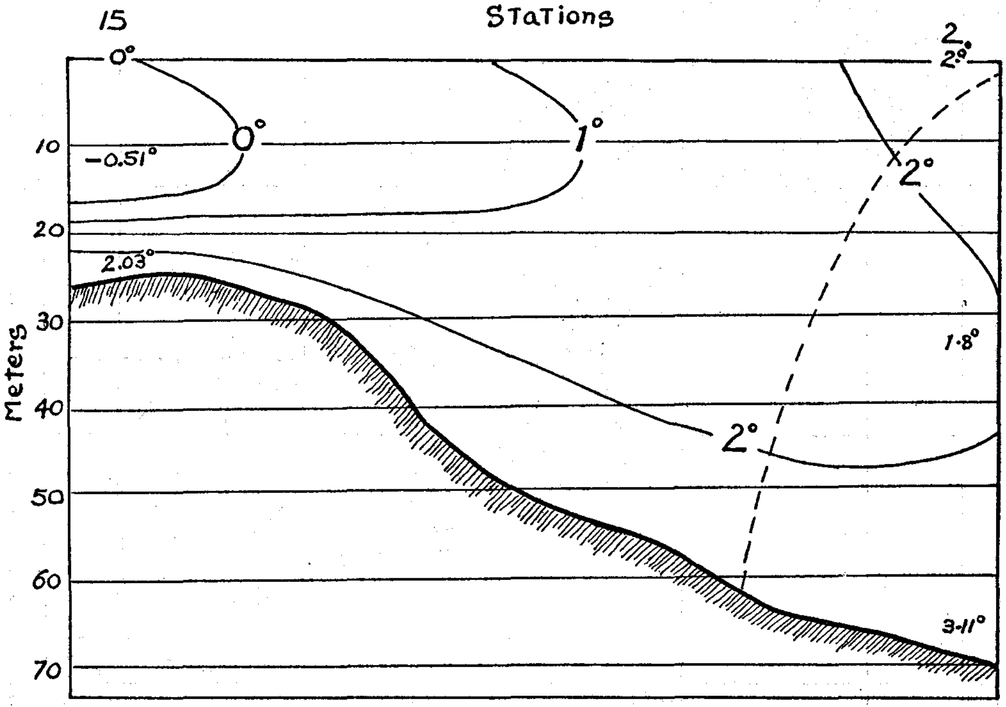

FIG. 83.—Temperature profile running from the Marshfield shore out into Massachusetts Bay, January 6 and 7, 2925 (*Fish Hawk* stations 2 and 15)

The mid-level proved colder than either the surface or the bottom in Massachusetts Bay on February 6 and 7, 1925, at 12 out of the 15 stations (fig. 82). At the same time the coldest stratum lay at a depth of 30 to 35 meters at the offshore line (*Fish Hawk* cruise 6, stations 19, 18, 2, and 4) but within 10 to 15 meters of the surface near the Plymouth-Marshfield shore.

Profiles running out from the land off Marshfield for January 6 and 7 (fig. 83) and for February 6 and 7 (fig. 84) show a very interesting succession, with the water that had been cooled near shore moving out from the land and at the same time sinking, to develop a shelflike intrusion into the warmer water of the center of the bay. The profiles also suggest that the coldest water was produced even closer in to the coast line than the innermost of the two stations, and that the whole column was colder than 0° next this sector of the coast at about the end of January, down to a depth of 10 to 15 meters.

In 1925 the southern side of Massachusetts Bay had experienced its minimum temperature for the winter and had commenced to warm again by the last week in February, when the mean temperature of the surface (1.65°) was nearly 1° higher than it had been two weeks earlier, with a corresponding rise in mean bottom temperature from 0.95° to 1.68°. On the 24th the whole surface of the bay was close to 2° in temperature, a regional uniformity illustrated by readings of 2.2° a mile or two off Gloucester, in the one side of the bay, with 2° to 2.1° in the central parts and 2.3° near Provincetown (station 5) in the other side. The offshore drift of water, chilled next the Plymouth shore, had also slackened, if not entirely ceased (fig. 84).

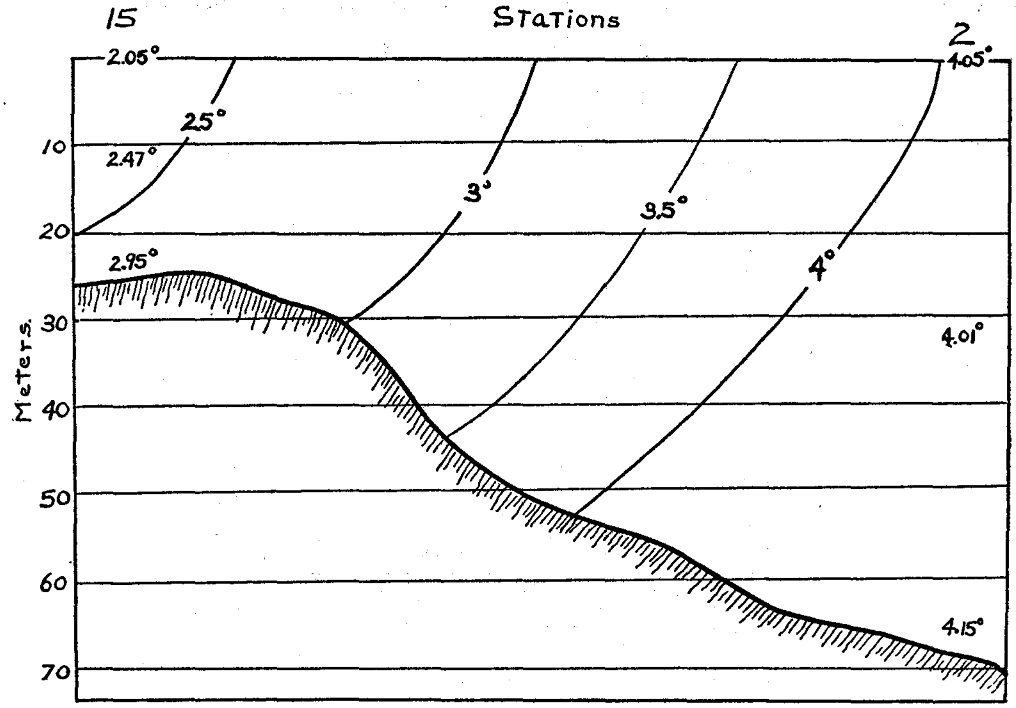

FIG. 84.—Temperature profile running from the Marshfield shore out into Massachusetts Bay, February 6, 7, and 27, 1925. The broken curve is the isotherm for 2° on February 24

The vertical distribution of temperature off Provincetown (*Fish Hawk* station 5) on February 24 is interesting because the bottom reading was the highest (2.34°) recorded for any level at any of these late February stations. A 40-meter salinity of about 33 per mille at 40 meters there, contrasted with 32.7 to 32.8 per mille in the central part of the bay, shows that some inflow through the bottom of the channel that separates Cape Cod from Stellwagen Bank was responsible for this unexpected warmth of the bottom water at the tip of the cape.

The facts that the inshore stations for the last week of February were slightly warmer at all levels than they had been three weeks previous, and that the water was slightly warmer inside Gloucester Harbor (2.78°) than a mile or two off the mouth (2.2°), instead of the reverse, are sufficient evidence that the coastal belt had begun to gain heat from the sun faster than it was losing heat by radiation from its surface. This gain was not yet rapid enough, however, to have produced any general differentiation in temperature between surface and underlying water in the moderate depths of Massachusetts Bay; and periods of severely cold weather may be expected to cause temporary reversals during the first weeks. In fact, a setback of this sort seems to have occurred between the 25th and 27th of that February, because the *Fish Hawk* once more found the water off the mouth of Plymouth Harbor coldest at the surface on the latter date, after three days of severe cold accompanied by a northwest gale Thus, the shoals seem to have acted as a temporary center for cooling there, as might be expected.

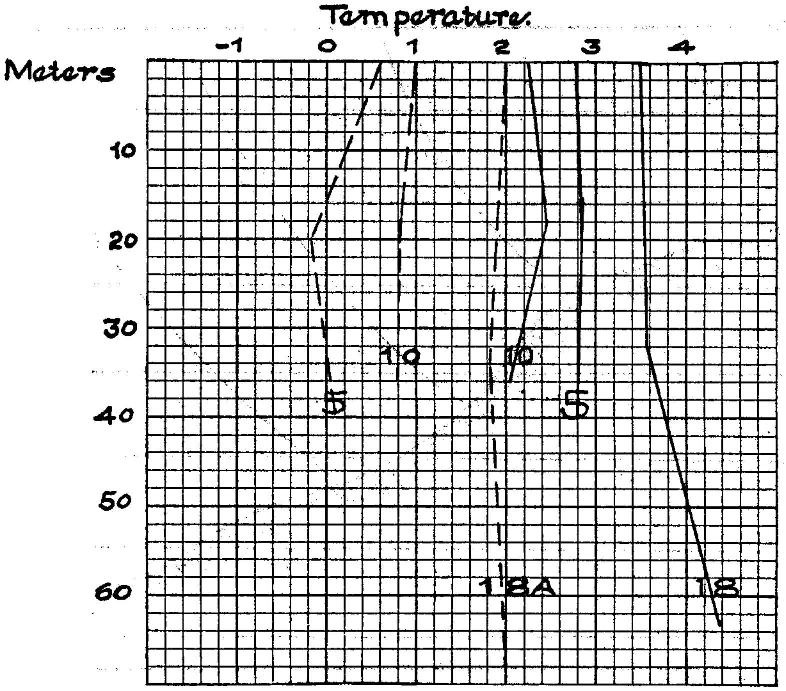

FIG. 85.—Temperature at three representative stations (5, 10, and 18 to 18A) in the southern side of Massachusetts Bay on January 6 and 7, 1925 (solid curves), and on February 6 and 7 (broken curves), to show change in one month

The winter of 1912–13 seems to have been about as cool as 1924–25 in Massachusetts Bay, minimum temperatures slightly higher (2.8° at surface and at 46 meters, 3.11° at 82 meters, February 13, 1913) being associated with the situation of the standard station well out in the mouth of the bay. February, 1921, was measurably warmer, with 3.3° at the surface, 3.52° at 20 meters, and 3.63° at 40 meters 1½ miles off Gloucester Harbor on the 9th (p. 994), where the surface reading was 1.67° on the 6th in 1925. After the almost Arctic February of 1920, the *Albatross* found the surface about 1.1° on March 1 on the run from Boston out to station 20050 at the mouth of the bay, and the open gulf correspondingly low in temperature, as described above (p. 522).[48]

It is also probable that the temperature of the water did not begin to rise in 1920 until after the first of March, instead of gaining heat from the middle of February, as happened in 1913 and in 1925; but rising temperatures may be expected in Massachusetts Bay by the last of February in all but the tardiest seasons.

It would be interesting to compare the midwinter temperature of Massachusetts Bay with that of the Bay of Fundy in the opposite side of the gulf. Unfortunately, the winter data so far available do not sufficiently establish the relationship between the two regions because they are for different years, except that there is no great difference between them at the coldest season.

Depth	Massachusetts Bay Feb. 6 and 7, 1925		Feb. 13, 1913, off Gloucester, station 10053	Feb. 7, 1917, Bay of Fundy (Mavor, 1923)
	Fish Hawk Station 18A	Fish Hawk Station 2		
	°*C.*	°*C.*	°*C.*	°*C.*
Surface	2.00	2.00	2.83	1.46
30 meters				1.99
30–34 meters	1.85	1.81		
46 meters			2.78	
50 meters				2.44
64–68 meters	2.00	3.10		
75 meters				3.12
82 meters			3.11	

Passamaquoddy Bay, tributary to the Bay of Fundy, seems also to correspond closely to Cape Cod Bay in minimum temperature, its inclosed situation so exposing it to climatic chilling that its surface falls close to the freezing point. Thus, Doctor McMurrich's notes (p. 513) record a temperature of about −1.7° at St. Andrews from February 16 to March 3 in the very cold winter of 1916, compared with a minimum of −1.55° in Cape Cod Bay on February 6 and 7 of the more moderate season of 1925 (*Fish Hawk* cruise 6, station 6A). Willey (1921) also records −0.77° at 20 meters depth in Passamaquoddy Bay on February 23 1917, which is about the expectation for Boston Harbor and probably for the inner parts of Casco Bay and of Penobscot Bay.

Neither is the difference of latitude between the Bay of Fundy and Massachusetts Bay accompanied by more than a week's difference, or so, between the dates when vernal warming becomes effective in the two regions. Thus, the trough of the Bay of Fundy commenced to warm about the first of March in 1917 (Mavor, 1923), and while Doctor McMurrich's plankton notes for St. Andrews do not show a rise in temperature until the end of that month in 1916, this was even a more tardy spring than 1920.

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[48] The surface of Massachusetts Bay is recorded as 3.3° on Feb. 24, 1920 (Bureau of Fisheries Document No. 897, p. 183); but this is simply the quartermaster's record.

During the winter of 1919–20 the water of Gloucester Harbor (fig. 29) chilled to about −1.5° and was colder than 0° from about January 12 to March 20; Boothbay Harbor (fig. 30) chilled nearly to −2° and was below 0° from January 5 to March 5; Lubec Narrows (fig.31), where tidal mixture with the water outside is more active, chilled to about the same temperature as Gloucester and was colder than zero for a slightly longer period—January 5 to March 20. In such situations, then, the strength of the tides and the frequency with which the water is renewed from outside govern the minimum to which the temperature drops in winter more than the latitude does.

THERMAL SUMMARIES

Summaries of the thermal cyles for the following representative localities are given: (1) Mouth of Massachusetts Bay, off Gloucester; (2) the Fundy Deep, between Grand Manan and Nova Scotia; (3) near Mount Desert Island; and (4) the western side of the basin of the gulf in the offing of Cape Ann.

1. MOUTH OF MASSACHUSETTS BAY, OFF GLOUCESTER

Temperatures at various dates, to 0.1°, some by direct observation and others by interpolation

Depth	Mar. 1, 1920 20050	Mar. 4, 1913 10054	Mar. 19, 1924	Apr. 7, 1925, Fish Hawk station 31	Apr. 3, 1913 10055	Apr. 9, 1920 20090	May 4, 1920 20120
Surface	2.5	2.9	2.2	4.1	4.1	3.3	6.4
20 meters	1.9	2.9	1.9	3.4	4.1	2.5	4.7
40 meters	1.9	3.0	1.8	3.0	4.0	2.4	4.3
70 meters	1.7	3.4	1.8	2.8	4.0	2.4	2.7
100 meters	1.5	----------	----------	----------	----------	2.3	----------

Depth	May 4, 1915 10266	May 16, 1920 20124	May 26, 1915 10279	June 16–17, 1925 Fish Hawk station 31	July 10, 1912 10341	July 19, 1916 10341	Aug. 9, 1913 10087
Surface	6.1	9.7	10.0	12.9	18.3	16.4	16.7
20 meters	4.0	5.1	7.2	5.5	9.0	6.0	10.4
40 meters	3.6	2.9	5.2	4.0	6.6	4.1	6.7
70 meters	3.6	2.8	3.8	3.6	4.6	3.7	6.3
100 meters	3.6	2.7	----------	----------	4.6	----------	5.2

Depth	Aug. 22, 1914 10253	Aug. 22, 1922 10632	Aug. 22, 1922 10633	Aug. 31, 1915 10306	Sept. 29, 1915 10320	Oct. 1, 1915 10324	Oct. 27, 1915 10339
Surface	18.9	18.00	18.7	16.1	10.5	10.3	10.8
20 meters	12.0	9.10	12.3	12.0	10.6	10.0	----------
40 meters	6.5	7.40	7.0	8.3	10.1	9.0	----------
70 meters	5.3	4.70	----------	6.7	7.0	7.5	7.3
100 meters	4.6	----------	----------	6.0	----------	7.1	----------

Depth	Oct. 31, 1916 10399	Nov. 20, 1912 10047	Dec. 4, 1912 10048	Dec. 23, 1912 10049	Dec. 29, 1920 10489	Jan. 16, 1913 10050	Feb. 9, 1921 10504	Feb. 13, 1913 10053
Surface	10.0	9.2	8.1	6.9	5.6	5.4	3.3	2.8
20 meters	9.6	9.0	7.8	6.9	6.0	5.4	3.5	2.8
40 meters	8.2	9.0	7.8	6.9	6.9	5.3	3.6	2.8
70 meters	6.1	----------	7.8	6.9	6.9	5.6	----------	3.0
100 meters	5.4	----------	----------	----------	7.0	----------	----------	----------

In this region (fig. 86) the most obvious seasonal change is the very rapid warming of the surface, which takes place from the end of the winter until about the end of July, resulting (on the average) in a rise of nearly 17°. After the first month or so of vernal warming (March to April), during which the whole column warms nearly uniformly, the rate at which the temperature rises becomes inversely proportional to the depth; and it so continues throughout the spring and summer, primarily because the source of heat is from above and secondarily because the vertical circulation is not sufficiently active to prevent a constant increase in vertical stability as the upper strata becomes warmer and warmer. The steadily widening spread between the curves for the surface and for the 20-meter level thus mirrors increasing stability. The result of this partial insulation of the deeper strata from the penetration of heat from above is that the maximum temperature for the year is

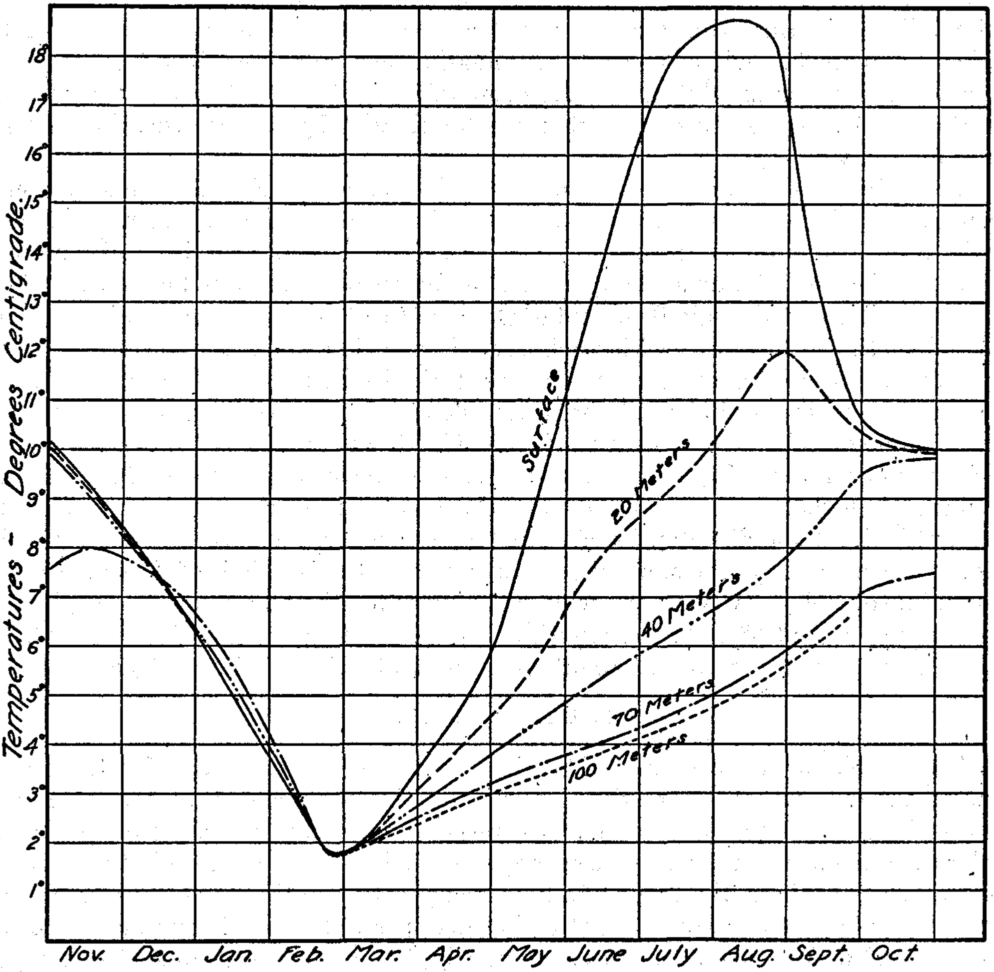

FIG. 86.—Composite diagram of the normal seasonal variation of temperature at the mouth of Massachusetts Bay, off Gloucester, at the surface, 20 meters, 40 meters, 70 meters, and 100 meters. The curves are smoothed. The station for August 9, 1923, is omitted because the water between the 20 and 150 meter levels was much colder that summer than usual, after an unusually cold winter

reached later and later in the season, at greater and greater depths, with the water continuing to warm at any given level until the autumnal cooling of the surface brings the temperature of the overlying mass down nearly as low. Thus, the surface is warmest in August, the 20-meter level about the first week of September, the 40-meter level not until October, and the 70-meter level in November, while the 100-meter temperature probably does not reach the maximum for the year until the first part of December. This has the interesting biologic complement that while any animal living in the littoral zone, or pelagic close to the surface, encounters the highest temperature while the solar illumination has fallen but little from its maximum intensity, for inhabitants of the deep water in 70 to 100 meters the summer, as measured by temperature, falls when the illumination by the sun is nearing its minimum for the year.

Sometime in July the warming of the surface suddenly slows down as the sun's declination falls lower and lower; but the cooling that takes place during September no doubt is due more to vertical mixing than to the loss of heat by radiation from the water, because the mean temperature of the air does not fall below that of the surface until about the middle or end of October (p. 671). The two chilling agencies that affect the surface of the Massachusetts Bay region—i. e., the constantly lowering temperature of the air and the incessant tidal stirring that becomes more and more active as the stability of the water decreases—make the whole column virtually homogeneous in temperature (about 9°) down to 100 meters depth by the beginning of winter. From that date on we have never found the surface differing by more than 2.5° in temperature from the bottom in any part of Massachusetts Bay until March; and in depths of 70 meters, or deeper, the bottom water is usually slightly warmer than the superficial stratum from the last half of December until the middle of February, with the winter minimum for the whole column usually falling between 2° and 3°. At the mouth of the bay, 7 to 12 miles off Gloucester, the temperature is at its minimum about the middle of February in most years.

2. BAY OF FUNDY

The graph for Massachusetts Bay illustrates the thermal cycle for the coastal zone of the gulf where least stirred, vertically, by the tides; that for the Bay of Fundy shows the opposite extreme. Corresponding to this difference in circulation under the influence of a much more severe winter climate and a somewhat cooler summer in the atmosphere, the graph of annual temperature in the Bay of Fundy (fig. 87) shows a vertical range of only about 5° in the upper 100 meters in summer, contrasting with 14° in Massachusetts Bay. Similarly, the annual range of surface temperture is only about 10°; 17° or 18° at the mouth of Massachusetts Bay. At 100 meters, however, the annual range (approximately 5°) is about the same for the two localities. Although the Bay of Fundy is much less stratified, with regard to temperature, than is Massachusetts Bay during the warm months, it is more so during the winter, with the surface 1° to 1.5° colder than the 100-meter level between the dates when the whole column becomes homogeneous in temperature in autumn and again in early spring.

In normal years the surface of the Bay of Fundy reaches its highest temperature in August or early September (slightly later than the date when the surface of

Massachusetts Bay is warmest), the 20-meter level early in September, 40-meter level about the 1st of October, and the 70-meter and 100-meter levels during that month or the next.

3. NEAR MOUNT DESERT ISLAND

Off Mount Desert, where tidal stirring keeps the water thoroughly mixed, surface to bottom, throughout the year, the column cools nearly uniformly at all levels during the autumn and warms only slightly more rapidly at the surface than in the deeper strata during the spring (fig. 88), so that the period when the surface is more than 1.5° to 2° warmer than the 20 to 40 meter level averages 2 to 3 months instead of 5 to 6 months, as in Massachusetts Bay; and the 40-meter level warms to its maximum for the year only a month or so later than the surface, instead of about 2 months later. The autumnal equalization of temperature also takes place by the first week of October near Mount Desert, a month earlier than in the deep part of the Bay of Fundy (fig. 87) but only a week or two earlier than in Massachusetts Bay (fig. 86).

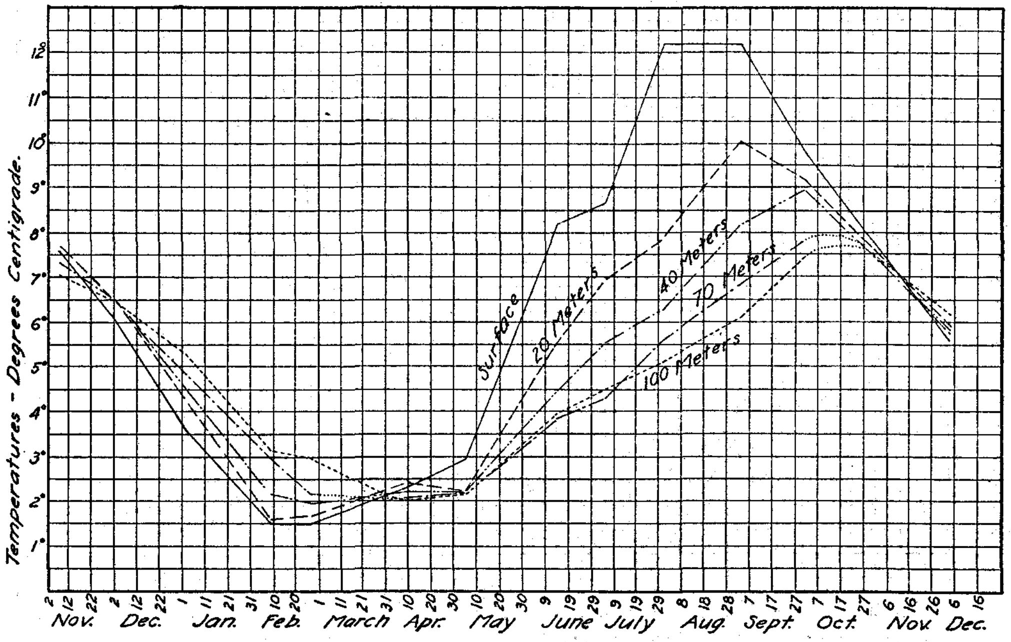

FIG. 87.—Composite diagram of the seasonal variations of temperature at *Prince* station 3, in the Bay of Fundy, between Grand Manan and Petite Passage, from November, 1916, to November, 1917, from Mavor's (1923) data

4. WESTERN SIDE OF THE BASIN

Probably the western arm of the basin (fig. 89) is less subject to tidal stirring in its upper strata than any other part of the gulf. Therefore, it is not surprising to find the seasonal rise and fall of temperature of its superficial stratum (surface to 40 meters) closely reproducing that of Massachusetts Bay, except that the temperature does not fall quite as low in winter, being farther offshore. The date when the temperature rises to its maximum for the year is also about the same here as in the bay—mid-August for the surface, late August or early September for the 20-meter level—but in 1920 this part of the basin was not coldest until about the last week in March, whereas the surface in the neighborhood of Gloucester had begun to warm by the end of February, a difference corresponding to the difference in location (p. 694). Vernal warming is also generally parallel at these two locations down to the 40-meter level; but it can readily be appreciated that any upwelling of the much colder bottom water at any time from June to October would interrupt the orderly progression of the 40-meter temperature, and it is probable that the very low 40-meter reading recorded off Cape Cod for August 22, 1914 (station 10254, 5.75°) is to be accounted for on this basis. Lacking data for late September or early October, I can not definitely state whether the 40-meter level of this side of the basin warms to its annual maximum at about the same date as in Massachusetts Bay (September).

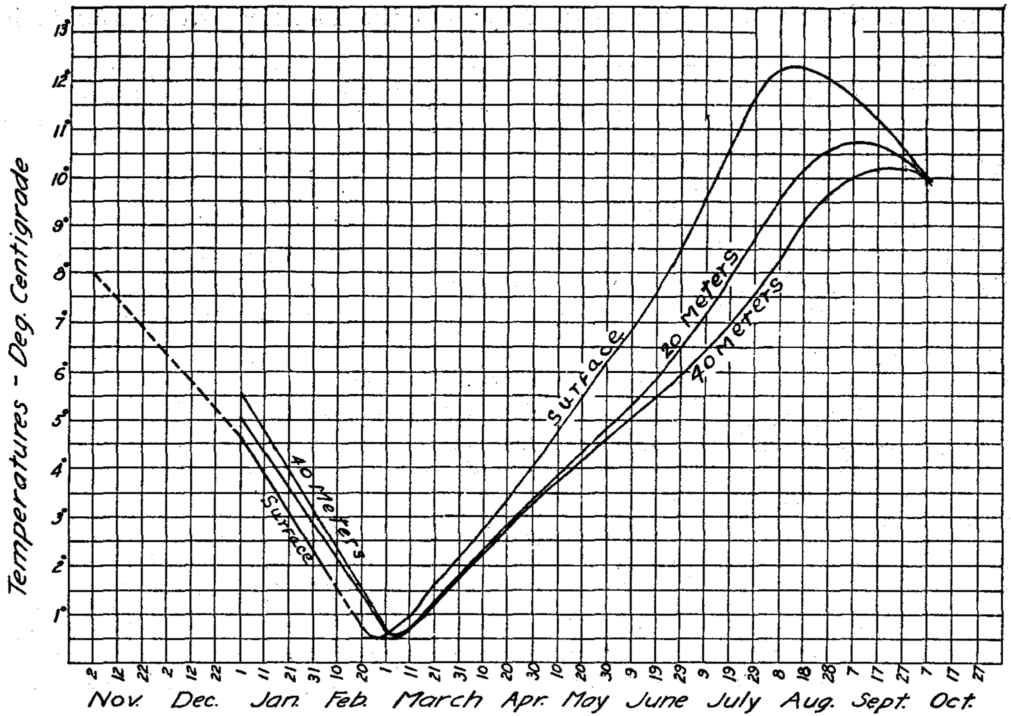

FIG. 88.—Composite diagram of the normal seasonal variations of temperature near Mount Desert Island, at the surface, 20 meters, and 40 meters, from data for the years 1915, 1920, 1921, and 1923. The curves are smoothed

The amplitude of the seasonal variation in temperature is nearly the same in the superficial stratum of the basin off the mouth of Massachusetts Bay as within the latter— i. e., a range of about 17° to 19° from summer to winter at the surface, about 10° to 11° at 20 meters, and about 7° to 8° at 40 meters. Unfortunately the only autumnal data for the deeper levels (100 and 150 meters) were for October and November of the very cold year 1916, when these underlying strata certainly had not warmed to the temperature usual for the date, although the superficial strata had (p. 642); but warming is probably to be expected here at 100 meters until some time in December. However, no rule can be laid down for depths greater than 100 to 150 meters in the basin. Thus, the lowest temperature so far recorded in the western side of the basin at 150 meters was for midsummer (1912) instead of at the end of the winter, as is the case off Gloucester only 30 miles to the westward. This lack of conformity between the season of the year and the temperature is still more notable at 200 meters, for which level the lowest as well as the highest temperatures for this locality have been recorded in summer, the latter (6.3° and 6.8°) in August, 1914 and 1915, and the former (4.61°) on July 15, 1912.

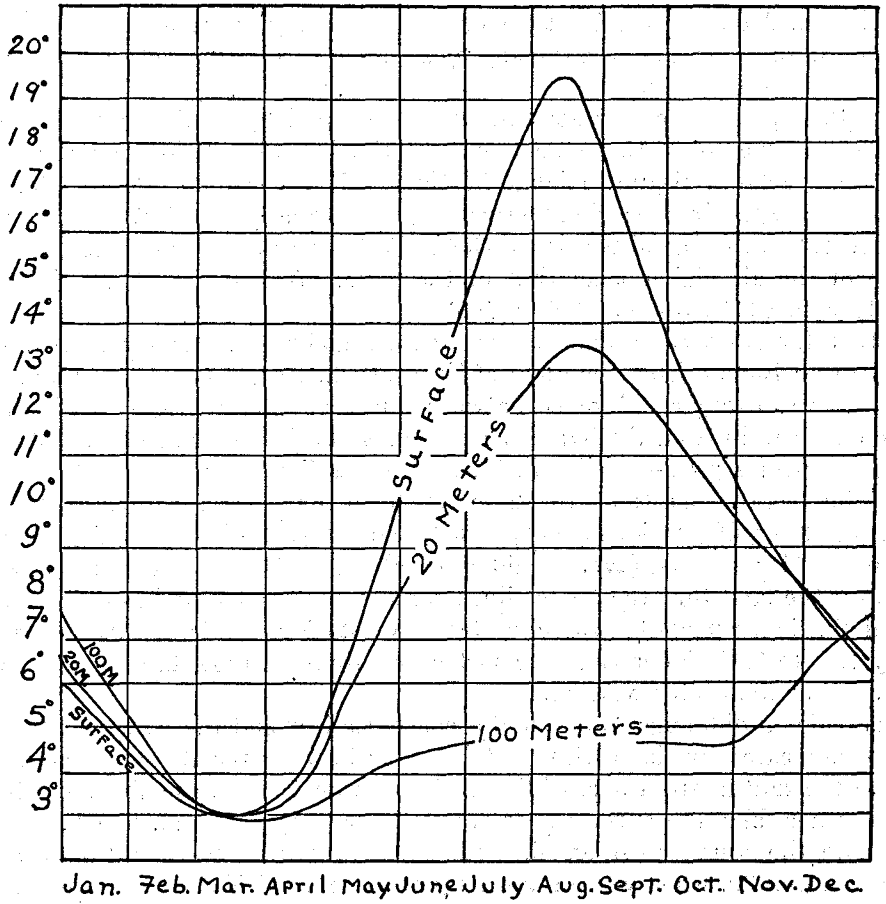

FIG. 89.—Normal seasonal variations in temperature at the surface, 20 meters, and 100 meters in the western side of the basin of the gulf, in the offing of Cape Ann, combined from the data for the several years and months. The curves are smoothed

RELATIONSHIP BETWEEN THE TEMPERATURE OF THE SURFACE AND OF THE AIR

The daily air and surface temperatures for Gloucester, Boothbay, and Lubec for the year 1919–20 (figs. 29 to 31) show the air constantly warmer than the water along the western and northern shores of the gulf from the middle of that March until late in October, a difference averaging greatest from some time in June until the last half of August. During the summer the 10-day averages for air and water frequently differ by 4° C.—occasionally by as much as 7°—and very hot days would show a still wider divergence.

The 10-day averages for air and water recorded by Rathbun (1887) for the years 1881 to 1885 are of the same tenure at the following lighthouses: Thatchers Island, Boon Island, Seguin Island, Matinicus Rock, Mount Desert Rock, and Petit Manan, with air averaging warmer than water after the first half of March. At Eastport, too, the Signal Service of the United States Army found the mean temperature of the air higher than that of the water after March 21 for the 10-year period, 1878 to 1887 (Moore, 1898, p. 409).

In 1920 the *Albatross*[49] found the air averaging about 1.7° colder than the water across Georges Bank during the night of February 22–23 and up to 1 p. m. of February 23, but the average difference between air and water was only 0.7° (day and night) on the run in from the bank to Massachusetts Bay on that date, with air and water temperatures precisely alike in Massachusetts Bay.

On March 2 to 4 (stations 10252 to 10260) in that year the surface of the central parts of the gulf (stations 20052, 20053, and 20054) still continued warmer than the air up to March 2 to 4 (average difference about 1.5° C.); but the air had warmed so fast over the land that the air readings for the coastal sector between Penobscot Bay and the inner part of Massachusetts Bay (stations 20055 to 20062) were consistently 1.1° to 5.6° higher than the surface readings by that date, night as well as day, averaging about 3.5° warmer.

This regional difference between the coastwise belt and the water farther out at sea had disappeared by the 10th to 11th of March, when the *Albatross* ran out from Boston to the southeastern part of the basin (station 20064), the air now being constantly warmer than the surface over the 24-hour period, 1 p. m. to 1 p. m. From that date on the hourly readings showed the air invariably warmer than the water, except on March 20, when we ran along the west coast of Nova Scotia to St. Marys Bay in a southeast storm with snow squalls.

Apart, then, from extremes of weather, the air averages warmer than the surface of the gulf from about March 10 on, though the precise date when this state is established varies from year to year and falls a week or more sooner near land than out in the central parts of the gulf.

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[49] Hourly temperatures, United States Bureau of Fisheries (1921, p. 183).

Amount by which the air was warmer than surface water, April 6 to 20, 1920

General locality	Station	Date	Time	Amount by which air was warmer than water, °C.
Off Boston Harbor	20089	Apr. 6	3 p. m.	5.5
Off Gloucester	20090	Apr. 9	10.15 a. m.	1.0
Off Cape Ann	20091	do	1.50 p. m.	5.7
Off Ipswich Bay	20092	do	5 p. m.	2.5
Off Isles of Shoals	20093	do	10.30 p. m.	.8
Platts Bank	20094	Apr. 10	3 a. m.	1.1
Near Cape Elizabeth	20095	do	8 a. m.	1.9
Off Seguin Island	20096	do	12.20 p. m.	9.4
Off Penobscot Bay	20097	do	11 p. m.	1.0
Near Mount Desert Rock	20098	Apr. 11	4 p. m.	3.6
Near Mount Desert Island	20099	Apr. 12	1 p. m.	6.3
Northeast part of basin	20100	do	4.30 p. m.	3.9
Do	20101	do	9.30 p. m.	3.5
Off Yarmouth, Nova Scotia	20102	Apr. 13	2.15 a. m.	3.9
German Bank	20103	Apr. 15	1 p. m.	6.7
Off Seal Island, Nova Scotia	20104	do	6 p. m.	4.7
North Channel	20105	do	9.15 p. m.	4.1
Browns Bank	20106	Apr. 16	12.20 a. m.	3.5
Eastern Channel	20107	do	4.35 a. m.	5.5
East edge of Georges Bank	20108	do	8.50 a. m.	6.4
Southeast slope of Georges Bank	20109	do	5 p. m.	5.8
East part of Georges Bank	20110	do	8.30 p. m.	6.1
Do	20111	Apr. 17	1.15 a. m.	3.6
Southeast part of basin	20112	do	5.35 a. m.	.7
Center of basin	20113	do	1 p. m.	3.8
Near Cashes Ledge	20114	do	8 p. m.	3.3
Basin off Cape Ann	20115	Apr. 18	3.40 p. m.	2.0
Off Cape Cod	20116	do	9.55 a. m.	3.0
Do	20117	do	1 p. m.	4.6
Cape Cod Bay	20118	Apr. 20	10.50 a. m.	8.8
Mouth of Massachusetts Bay	20119	do	8.20 p. m.	6.9

The air averaged about 5° warmer than the water in Massachusetts Bay, along Cape Cod, and out across Georges Bank to the continental edge by May 16 to 17, 1920 (run from station 20123 to station 20129), with the difference greatest (10°) in Massachusetts Bay from 10 a. m. to 1 p. m., least (1.4°) at 9 p. m., but increasing again to 4° to 5.5° over Georges Bank during the daylight hours of the next day.

In any partially inclosed body of water, such as the Gulf of Maine, where the wind may blow either out from the land over the water or in from the open sea, the relation of water to air temperature depends largely on the strength and direction of the wind at any particular moment. For instance, the *Halcyon* recorded an air temperature of 23.3° C. and surface reading of 14.44° while fishing on Platts Bank on July 27, 1924, at 5 a. m. in a flat calm; but shortly afterward a breeze coming in from the south—from the open sea—lowered the temperature of the air to 15.6°, with no change in the water. On the whole, however, the difference between air and water during the part of the year when the air is the warmer certainly rules greatest by day, when the sun's heat pours down, and least by night. For instance, the air was 3° to 4° warmer than the water from 7 a. m. to 5 p. m. on the run out to the basin off Cape Ann on July 15 to 16, 1912, and only about 1.5° to 2° warmer than the water from 9 p. m. to 1 a. m.

The hourly temperatures taken on our summer cruises have not yet been studied in detail, but preliminary examination shows that the spread between air and water continues of about this same order of magnitude over the open gulf from May until July, averaging about 0.3° to 5°.

Usually we have found the air at least 2° but seldom as much as 4° warmer than the water of the open gulf in August and September by day. This accords with Craigie and Chase's (1918, p. 130) and with Craigie's (1916a) records of air 2.2° to 6.24° warmer than surface over the Bay of Fundy generally during July, 1915, and air 2° to 3.8° warmer than water along a section of the bay from Grand Manan to Nova Scotia on August 27 to 29, 1914. Mavor's (1923) experience was also similar. (No night time records have been published for the Bay of Fundy.)

The only regional distinctions that I dare draw in this respect for the open gulf until the very considerable mass of material is more carefully analyzed, is that the difference between daytime temperatures of the air and of the water averages greatest near the shore, as was to be expected.

It is common knowledge that the air along our seaboard is often much warmer than the water that actually washes the coast during the warmest part of the summer. Thus, we find the air averaging 6° to 7° warmer than the water at Boothbay and Gloucester and in Lubec Channel about July 25, 1920 (figs. 29 to 31), with differences as wide as 10° C. (18° F.) on individual hot days.

Vachon (1918), too, found differences as great as 10° to 12° between the temperatures of air and water in Passamaquoddy Bay on individual days in July, August, and September, whereas the maximum difference between air and surface so far recorded for the open Bay of Fundy is only 7.34°; 8.3° for the Gulf of Maine outside the outer headlands (on August 16, 1912). The mean difference between air and surface temperatures for the Gulf of Maine as a whole will probably be found to fall between 2° and 5° for the summer.

We have occasionally found the surface slightly warmer than the air as early as the first week in August. In 1912, for example, the *Grampus*, running offshore from Cape Elizabeth in a flat calm and bright sun on August 7 and 8, found the water fractionally colder than the air early in the day, 1° to 1.5° warmer than the air from noon to 2 p. m., once more slightly colder than the air from 3 to 9 p. m.. and then again fractionally warmer than the latter from 10 p. m. until 1 a. m.

A period is next to be expected when the air will be cooler than the water during some of the nights, though still warming by day to a temperature higher than that of the water, presaging the date (sometime in October) when the mean temperature of the air falls permanently below that of the surface of the gulf, so to continue throughout the winter. The following table of hourly differences will illustrate this for one 24-hour period (August 15, 1 a. m., to August 16, 1 a. m.), during which the *Grampus* ran eastward from the vicinity of Mount Desert Rock toward the Grand Manan Channel.

Difference between surface and air temperatures (° C.)

[− signifies that the air was colder, + that it was the warmer]

Hour	Difference	Hour	Difference
August 15:		August 15—Continued.	
1 a.m.	+2.8	2 p.m.	+5.6
2 a.m.	+1.7	3 p.m.	+3.9
3 a.m.	+1.1	4 p.m.	+4.4
4 a.m.	+1.7	5 p.m.	+2.2
5 a.m.	−0.6	6 p.m.	+2.2
6 a.m.	−0.6	7 p.m.	+2.2
7 a.m.	+0.6	8 p.m.	+2.2
8 a.m.	+1.1	9 p.m.	−1.1
9 a.m.	+2.8	10 p.m.	−1.7
10 a.m.	+2.8	11 p.m.	−1.7
11 a.m.	+2.8	12 midnight	0.0
12 noon	+3.3	August 16: 1 a.m.	0.0
1 p.m.	+5.0		

It is to be noted that while the air temperature did not fall below that of the water until between 3 and 4 a. m. on the first night, this happened at 9 p. m. on the second.

In 1920 the air averaged colder than the water in the harbors of Gloucester, Boothbay, and Lubec after about the middle of October. According to the temperatures collected by Rathbun (1887), the surface was colder than the air at the several lighthouses after the following approximate dates of 1881 to 1883:

Locality	Year	Date
Pollock Rip	1882	After Nov. 16.
	1883	After Nov. 1.
Thatchers Island	1881	After Nov. 8.
	1882	Between Nov. 11 and 16.
Boon Island	1881	After Oct. 30.
	1882	After Nov. 1.
	1883	After Nov. 6.
Seguin Island	1881	After Nov. 1.
	1882	After Oct. 25.
	1883	Nov. 1 to 6.
Matinicus Rock	1881	After Oct. 17.
	1882	After Oct. 25.
	1883	Nov. 1 to 6.
Mount Desert Rock	1881	After Nov. 16, but with reversals.
	1882	After Nov. 16.
	1883	After Nov. 6.
Petit Manan	1881	After Nov. 8.
	1882	After Oct. 22.
	1883	After Nov. 26.

Thus the water in the coastal belt is constantly warmer than the air after the last week of October or the first week in November. From that time on the difference between air and water increases until the middle of January, when the air averages about as much colder than the water as it is warmer in summer (illustrated by the 10-day averages for Gloucester, Boothbay, and Lubec, figs. 29 to 31). During periods of extreme cold, such as come to New England and to the Maritime Provinces almost every winter, the spread between air and surface temperatures is even wider than the spread of the reverse order in summer. At Lubec, for example, the air averaged 10° the colder for 10 days in January, 9° the colder at Boothbay, and it may be more than 20° colder than the water in the western side of the gulf on the coldest days. Thus, on December 21, 1924, when the mean surface temperature of the southern side of Massachussetts Bay was about 4.3° (p. 650), the air temperature was −18° C. at Boston (p. 650). As another example I may cite December 17, 1919, when the air temperature was about −21.5° C. at Lubec (7° below zero F.), the temperature of the surface water being 0°.

In the winter of 1919–20 (a cold year) the air temperature averaged about 3.1° colder than the surface at Gloucester from December 2 to March 1 and about 5° colder than the water at Lubec. At Eastport the United States Army Signal Service found the mean water temperature to average about 6.6° warmer than that of the air for the period December to February during the 10 years 1878 to 1887.

The temperatures collected by Rathbun at lighthouses and lightships do not cover the months of January or February, and his statement (Rathbun, 1887, p. 166) that the reason for this omission is "the manifest errors of observation sometimes made during extremely cold weather" makes it doubtful how close an approximation to the truth is given by his averages for the last half of December. Consequently, it is necessary to turn to the observations taken on the *Halcyon* during December to January, 1920–21, for the relationship between the air and surface temperatures for the open gulf in midwinter; nor do these fairly represent its outer waters, all having been taken within 30 to 40 miles of land.

These *Halcyon* stations show the air 4.4° colder than the water off Boston Harbor (station 10488), but averaging about 2.5° colder than the water in the northeastern corner of the gulf and precisely the same as the water in the Fundy Deep (station 10499).

The records for this cruise would have been more fairly representative had it included any severely cold days, which it did not, for the obvious reason that when icy northwest gales sweep the gulf oceanographic research from a small ship becomes impossible. Nevertheless, the regional difference just sketched does illustrate the very important fact that the cold winds of winter are most effective as cooling agents close in to the land.

While no exact data are at hand for Georges Bank in early winter, general report has it that the temperature of the air is close to that of the water there in December and January, except when cold northwest gales blow out from the land or warm "southerlies" blow from the tropic water outside the edge of the continent.

From the oceanographic standpoint, the most instructive conclusion to be drawn from the relationship between the temperature of the air and that of the water is that the surface of the gulf follows the air in its seasonal changes (p. 699; Bigelow, 1915 and 1917). This, of course, is a corollary of its situation to leeward of the continent, with winds blowing from the land out over the sea for a much greater percentage of the time than vice versa, especially in winter. It follows from this, as I have emphasized in earlier publications, that the relation of sea climate to air climate is, on the whole, the reverse here of what applies to northwestern Europe, the surface of the sea responding rapidly in winter to the rigorous air climate.

How closely the winter temperature of the water of the harbors and bays tributary to the gulf depends on the influence of the land is illustrated by the fact that Gloucester

Harbor, which opens freely to the deeps off Massachusetts Bay, is 0.05° to 1° warmer than the more inclosed waters of Woods Hole in winter, although a degree of latitude farther north and bordering a colder ocean area (Bigelow, 1915, p. 257). Gloucester Harbor, in turn, is colder than the neighboring parts of Massachusetts Bay. For example, the surface temperature of the outer part of the harbor fell to about 0.5° to 1.1° during the winter of 1912–13, but the lowest reading a few miles outside was 2.78° (Bigelow, 1914a). Boothbay Harbor, 75 miles north of Gloucester and shut in by numerous islands, is likewise colder in winter than are the neighboring waters of the open gulf. On March 4, 1920, for instance, the temperature of the harbor was fractionally below 0° (fig. 30), at which date the *Albatross* had surface readings of 2.2° to 1.1° on the run in to the land there from a station some 35 miles offshore (20057). Information to the same effect results from an average March temperature of about 0.11° at the Bureau of Fisheries station at the head of Boothbay Harbor for March, 1881 to 1885, contrasting with 1.1° to 1.7° at Seguin Island (Rathbun, 1887). Finally, a graph (fig. 90) is offered to show the thermal progression of air and water in Massachusetts Bay during the winter of 1924 and 1925.

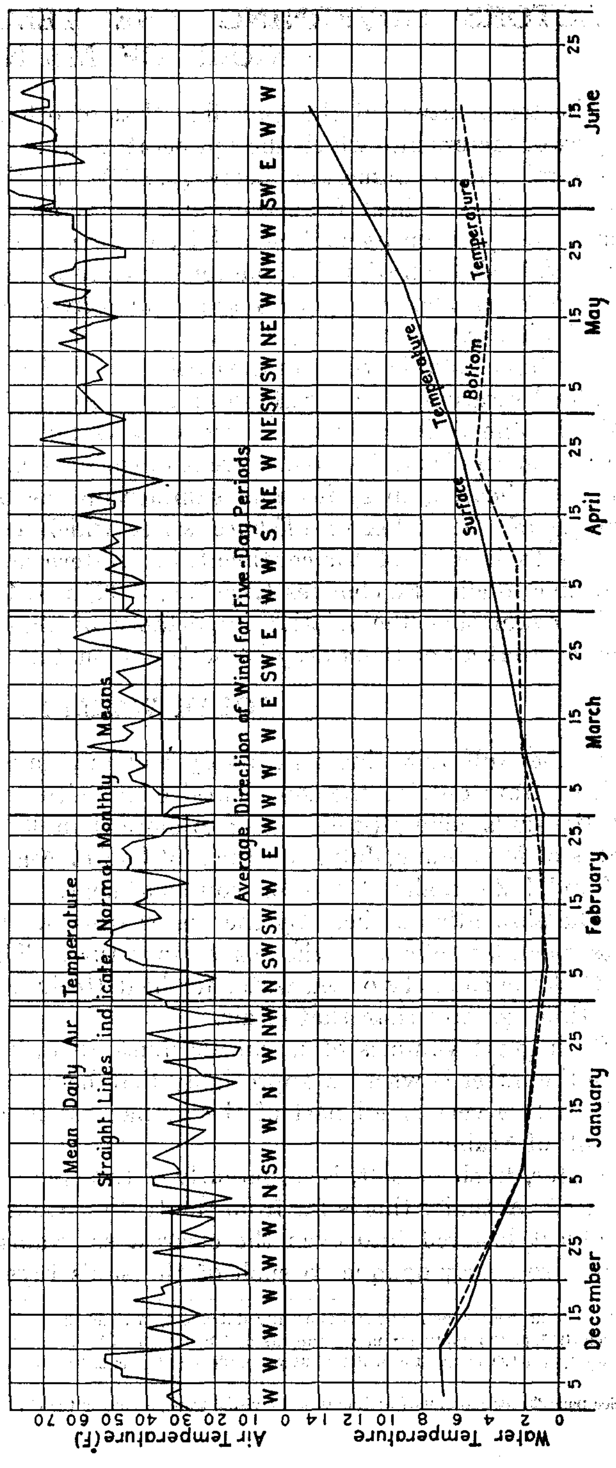

FIG. 90.—Surface and bottom temperatures off Plymouth, Mass. (*Fish Hawk* station 10, p. 1006); daily temperature of the air at Boston and direction of the prevailing wind from December 3, 1924, to June 17, 1925. Compiled by R. Parmenter

FACTORS GOVERNING THE TEMPERATURE OF THE GULF OF MAINE

The temperature of the gulf, like that of other boreal seas, is governed by a complex of factors into which the temperature of the water that enters the gulf from the several sources enumerated below (p. 854), warming by the sun's rays, and cooling by the radiation of heat from the water to the air in autumn and winter, as well as by evaporation from its surface and by the melting of snow (and locally of ice), all enter. Added to all of which the temperature at any given depth, date, and locality depends to a large degree on the local activity of vertical circulation, especially of tidal stirring.

Continued studies confirm the earlier generalization that the temperature of the superficial stratum of the gulf down to a depth of about 100 meters is governed chiefly by the chilling caused by rigorous winter climate and by the influx of cold water from the Nova Scotian current in spring, on the one hand, balanced against local solar heating in spring and summer, on the other, and against the warming influence of the influx of offshore water which enters its eastern side. As the gulf lies to leeward of the continent, its western and northern sides are the most responsive to climatic changes (Bigelow, 1922, p. 164).

In evaluating the relative importance of these several processes it is to be observed that all of them are distinctly seasonal in their effects.

SOLAR WARMING

In the Gulf of Maine, which very seldom is invaded by warm water from the south or from outside the continental edge—situated, too, at a temperate latitude, with the sun's noon altitude rising to more than 63° above the horizon during the months of May, June, July, and the first half of August—solar heating *in situ* is the chief and, indeed, almost the sole source of heat.

The absorption of heat by the water from warm air blowing over its surface exerts much less effect on the sea temperature. This last statement rests on the fact that the capacity of sea water for heat (technically its specific heat [50]) is about 3,000 times greater than that of air.

Such great volumes of warm air must, then, blow over the surface of the sea before the latter is warmed appreciably that heat from this source can be responsible for only a very small part of the vernal rise in temperature that characterizes the Gulf of Maine.

Water, fresh or salt, is apparently a transparent fluid when viewed in small volumes. Actually this is far from the truth. Consider, for example, how rapidly any object lowered into even the clearest sea vanishes from sight.[51] In fact, sea water is so nearly opaque to such of the sun's rays as convey most of its energy

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[50] The specific heat of distilled water is usually stated as 3,257 times that of air. Sea water has slightly less capacity for heat, Krümmel (1907, p. 279) quoting from experiments by Thoulet and Chevalier (1898), giving the specific heat of water of 30 per mille salinity as 0.939 and that of water of 35 per mille salinity as 0.932, both at 17.5° temperature, taking distilled water as unity.

[51] See page 822 for actual measurements of the visual transparency of the Gulf of Maine at various times and places.

that only a very thin surface stratum of the sea is warmed by direct solar radiation. Further transference of the heat so gained, downward to the deeper strata, depends on other processes, discussed below (p. 678).

Oceanographers, therefore, long have realized that the thickness of the stratum that receives the heat of the sun directly depends on the distribution of this energy along the solar spectrum and on the transparency or opacity of the water toward rays of different wave lengths, which, in turn, depends largely on the clarity or turbidity of the water.

The altitude of the sun—i. e., the angle at which its rays strike the surface of the water—and the roughness of the water determine what percentage of the total radiation is reflected and what percentage penetrates. No attempt has yet been made to measure this for the Gulf of Maine; but there is no reason to suppose that the latter differs much in this respect from Puget Sound, where Shelford and Gail (1922) found about 25 per cent of the light reflected or shut out by the surface mirror between 10 a. m. and 2 p. m. in calm weather, with the loss increasing to 60 to 70 per cent, or even more, when the sea was rough. On the average, then, about 50 per cent of the solar radiation falling upon the gulf may be expected to warm the latter; the remainder is lost, so far as any direct effect on the temperature of the water is concerned.[52]

When we attempt to estimate the warming effect which the 50 per cent or so that does penetrate actually exerts at any given level, we must keep clearly in mind the distinction between the intensity of radiation and the extreme penetration of light. The latter has been the subject of repeated experiments, and, as might be expected, successive tests with more and more delicate photographic apparatus have revealed faint light at greater and greater depths. The mere fact, however, that light penetrates to depths as great as 1,000 to 1,700 meters[53] in amount sufficient to affect photographic plates does not imply an equal penetration of radiant heat in measurable amount, witness the fact that stars—even nebulæ—can be photographed though their heat is not appreciable on the earth. On the contrary, theoretic calculation and practical experiments unite to prove that the intensity of solar radiation falls off very rapidly as the depth increases, especially for the longer wave lengths.[54]

Hulburt (1926) has found that sea water is slightly more opaque than fresh water for the shorter wave lengths but shows about the same coefficient of absorption as fresh water for the longer.

The long waves below the visible end of the spectrum (the so-called "infra red" or "heat" rays) convey more energy than all the rest of the spectrum combined, bringing from 51 to 67 per cent of that part of the total energy of the sun that penetrates to the earth's surface near sea level through air of the same general order of humidity as prevails over the Gulf of Maine (Abbott, 1911, p. 289). The precise percentage conveyed by these infra red rays varies with the altitude of the sun.

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[52] This is a much greater loss by reflection than Schmidt (1915) found for fresh-water lakes, where he records only a 6 per cent loss with the sun 30° above the horizon. Probably the state of the surface accounts for the difference

[53] See Helland-Hansen (1912); Grein (1913).

[54] For the coefficient of absorption of the visible part of the spectrum in pure water, see Krümmel (1907), Fowle (1920), and Kayser (1905).

I know of no direct measurements of the depth to which the infra red rays do actually carry heat into the sea water in measurable amount under the conditions of turbidity actually existing at sea, but even distilled water is so nearly opaque to them that they are almost entirely absorbed (for practical purposes, entirely so) in one meter, and their penetration into the sea is certainly less. That is to say, nearly half of the sun's direct radiant heat is expended, theoretically, upon this thin surface film.

According to a calculation carried out in the physical laboratory of Harvard University through the kindness of Prof. Theodore Lyman, 58 per cent of the energy conveyed by the visible part of the solar spectrum would be absorbed by passage through 9 meters more (i. e., a total of 10 meters) of perfectly clear distilled water, so that only about 20 per cent of the total solar energy entering the water would penetrate as deep as 10 meters, this small residual lying chiefly in the blue-green part of the spectrum. Certainly less than 1 per cent could penetrate as deep as 200 meters—chiefly in the ultra violet. Probably this calculation would apply equally to pure salt water. The sea, however, is never clear; and in boreal coastwise waters such as the Gulf of Maine, which are always comparatively turbid, the fine particles in suspension—silt or plankton—absorb so much of the sun's rays that the penetration of heat is much reduced.

It is, of course, with the depth to which the water of the gulf is measurably warmed by the direct penetration of solar radiation under conditions actually prevailing there that we are now concerned. This may be approximated by experiments that have been made in other seas. In the comparatively clear water of the Mediterranean, off Monaco, Grein's (1913) measurements[55] of the penetration of different parts of the solar spectrum showed that the wave lengths as long as the blue-green, and longer, were virtually all absorbed in the upper 50 meters, red-yellow in the upper 10 meters, as appears in the following table condensed from his account.

Intensity of light penetrating to different depths, taking the amount at 1 meter as 100

Depth, meters	Color and wave length					
	Red, 680–610	Orange-yellow, 620–585	Green, 570–486	Blue-green, 515–486	Blue, 475–420	Blue-violet, 435–400
1	100.00000	100.0000	100.0000	100.0000	100.000	100.0
10	.27000	.2000	16.6000	16.6000	43.700	80.0
50	.00021	.0032	.2200	.2500	20.100	20.0
100	--------	.0001	.0030	.0033	.550	1.0
200	--------	--------	.0004	.0010	.004	.1

Translated into terms of solar energy, this means that at least 70 per cent of all the radiant solar heat that penetrated as deep as 1 meter was absorbed at a depth of 10 meters; and as nearly all of the energy of the infra red certainly was absorbed in that upper meter of water, it is not likely that more than 13 per cent of the solar heat that entered the water at all reached as deep as 10 meters by direct radiation,

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[55] These experiments were made with a "revolving photometer," for description of which, and of the method by which the degree of blackening of the photographic plates was measured, see Grein (1913).

and virtually all of this residue was absorbed shoaler than 50 meters. Grein's exacting measurements, therefore, confirm Knott's (1904) conclusion that a. m. and p. m. temperatures taken by the "Pola" at 16 pairs of stations, with thermometers graduated to 0.1° C., showed no evidence of the penetration of direct solar radiation deeper than about 20 meters.

In more turbid northern seas we may expect the solar radiation to be absorbed in a still shoaler surface stratum, depending largely on the character and abundance of the plankton at the time. In Puget Sound, for example, Shelford and Gail (1922) found the first meter of water absorbing about 20 per cent of the visible light that actually penetrates below the surface, with only 8 to 10 per cent of even the shorter wave lengths reaching a depth of 10 meters under average illumination.

In the English Channel, Poole and Atkins (1926) found the illumination at 20 meters to be about 5.5 per cent as strong as just below the surface; while in the Bay of Fundy, according to Klugh (1925), only about 1.5 per cent of the illumination recorded just below the surface penetrates to 10 meters in August in bright sunlight.

In Lake Seneca, New York (probably still more turbid), Birge and Juday (1921) found that only 15 per cent of the solar energy that entered the water penetrated to a depth of 2 meters, 5.4 per cent to 5 meters, and only 1 per cent to 10 meters. Perhaps as striking an example as any in nature of the absorption of the sun's heat by the uppermost stratum of water is afforded by certain oft-quoted salt-water basins along the west coast of Norway, in which the salinity is very low at the surface but so high from the depth of 1 meter downward that the water is in extremely stable equilibrium. Here solar radiation in summer induces temperatures as high as 20° to 30° in the upper 2 meters of water but hardly affects the temperature deeper than about 5 meters. (See Helland-Hansen, 1912a, p. 65, for a discussion of these "Polls," as they are named locally.)

Judging from the similarity in latitude and in general hydrographic conditions, the penetration of solar radiation is probably of about the same order of magnitude in the open Gulf of Maine as in Puget Sound. If, then, the water of the gulf were entirely without motion, and if heat were conveyed downward by no other means than direct solar radiation, more than 90 per cent of such of the sun's radiant energy as penetrated the water at all would be expended within 10 meters of the surface, something like 98 per cent within 25 meters of the surface, and all but a fraction of 1 per cent at a depth of 100 meters. At times of year when the water was particularly turbid—spring, for example, during the active flowerings of diatoms—the solar radiation would be absorbed still more rapidly.

We must also bear in mind that that part of the sun's insulation which is intercepted by the superficial stratum of water does not act solely to warm the latter, but that a part of its energy is expended directly in evaporating water vapor from the surface (p. 680).

Under the conditions existing in the gulf it seems that if direct solar radiation warms the surface by 20° at any given locality in the gulf, the 10-meter level would certainly warm by only about 2°, very probably the 50-meter level would warm by no more than 0.2°, and the 100-meter level would not suffer change sufficient for our most delicate deep-sea thermometers to record during the part of the year when the water is gaining heat, unless this heat were carried downward into the deeps by some other process. The warming by direct solar radiation would therefore be virtually negligible during a single summer at depths greater than about 50 meters if there were no vertical circulation, this limit varying with varying states of turbidity and with the roughness or smoothness of the surface of the water as well as with the cloudiness of the sky, the haziness of the atmosphere, the percentage of foggy days, etc.

DISPERSAL OF HEAT DOWNWARD INTO THE WATER

With at least nine-tenths of the solar energy that enters the water of the gulf at all absorbed within 10 meters of the surface, and virtually all of it shoaler than 30 to 50 meters, the importance of vertical circulation in carrying down into the deeps water that has been warmed at the surface, and by bringing cold water up within the influence of the sun from below, becomes at once apparent.[56]

The vertical circulation of the gulf is discussed in another chapter (p. 924). It concerns us here, however, as the factor that chiefly governs the temperature of the mid-stratum between the depths of, say, 25 and 100 meters. In different parts of the gulf and at different seasons we find all gradations from water so stable, vertically, and with currents so weak that virtually no interchange takes place between the different strata, to the opposite extreme where the whole column is kept so thoroughly churned by tidal currents that the heat absorbed by the surface is uniformly dispersed downward. This last state characterizes nearly the entire area of the gulf during the first days of spring and is responsible for the fact that the whole upper stratum, down to 100 meters, at first warms at so nearly uniform a rate.

The vertical uniformity of temperature that characterizes Nantucket Shoals, locally, too, Georges Bank, parts of the Bay of Fundy, and the coastal belt along the west coast of Nova Scotia, results similarly from tidal stirring so active that it overcomes the tendency of the water to become stable as the spring progresses. Off the western shores of the gulf, however, where tidal stirring is not active enough to counteract the increasing stability of the column induced by the warming of the surface, the development of a light stratum at the surface tends more and more to insulate the deeper strata of water from the effects of solar warming as the season advances. The more stable the water becomes, the more effectively are the deeper strata protected in this way from thermal influences from above.

It is this obstacle, which the stable state of the water opposes to vertical circulation during the warm half of the year, which is responsible for the fact that the temperature rises so much more rapidly and to so much higher a value at the surface than only a few meters down, and which allows the persistence of much lower temperatures at depths of only 50 to 100 meters all summer. However, there is always enough vertical movement of the water everywhere in the Gulf of Maine to prevent this insulation of the deeper strata from becoming as effective as it is along the coast from New York, southward, during some springs (Bigelow, 1922).

Observations taken during our first cruises in 1912 (Bigelow, 1914) pointed to local differences in the strength of the tidal currents as chiefly responsible for the fact that the surface is so much colder, but the bottom, depth for depth, so much warmer along the coast of Maine east of Penobscot Bay and in the Bay of Fundy

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[56] Conduction and the radiation of heat from one particle of heat to the next are negligible in this respect. (Wegemann, 1905; Krümmel, 1907.)

than it is off the western shores of the gulf in summer. The following exposition may more graphically explain this general phase of the gulf temperatures:

Let us assume two localities, both with an initial temperature of 2°, surface to bottom, but with vernal heating in the first (*a*) uniformally propagated downward through the whole column to a depth of 50 meters by active tidal stirring, but absorbed in regularly increasing ratio, with increasing depth, at the second (*b*), to *nil* at the bottom. If enough heat were received at the surface to warm the whole column at *a* to a temperature of 10°, the same amount of heat entering the water at *b* would warm the surface to 20° there, but not affect the temperature at all 50 meters down. The ideal condition represented by *a* is most closely paralled in the Gulf of Maine area by the most tide-swept parts of the Bay of Fundy region. An approximation to the vertical distribution of temperature at *b* is to be found in the western side of the basin off Cape Ann, where the surface warms from a winter minimum of about 3° in February to a summer maximum of about 19° to 20° in August, but where the temperature of the 50-meter level rises by only about 1° during the same interval. The relative rates at which heat is dispersed downward in these two parts of the Gulf of Maine correspond directly to the relative activity of the tidal currents, which are weaker in the deep water in the offing of Cape Ann than anywhere else in the Gulf of Maine.

THERMAL EFFECTS OF UPWELLINGS

Upwellings of water from below have little effect on the temperature of the surface stratum of the gulf in winter, because the whole column of water is then so nearly homogeneous that the rising currents have about the same temperature as the water which they replace. From April on, however, the upwellings that follow offshore winds in the western side of the gulf are reflected in a chilling of the surface, as described above (p. 550). This is not the case in the eastern side, however, or on the banks, where tidal stirring keeps the water more nearly homogeneous, vertically, throughout the warm season as well as the cold. The relationship between these upwellings from small depths and the temperature of the surface water is sufficiently described in connection with the midsummer state of the gulf (p. 588). I need only add that the thermal effect of vertical circulation of this sort along our New England coast has long been appreciated and has recently been discussed by Brooks (1920).

THERMAL EFFECTS OF HORIZONTAL CIRCULATION WITHIN THE GULF

The effects of the transference of cold water by the Nova Scotian current is discussed below (p. 680). A word is also in order as to the opposite process. The transference of heat, from the tropics to high latitudes, by the great ocean currents, is reflected on a very small scale in the Gulf of Maine in summer by the drift of surface water, warmed in the western side, across to Nova Scotia by the dominant anticlockwise drift. The outflow from the eastern end of Nantucket Sound, now reasonably established (p. 886), must similarly tend to raise the temperature of the water over Nantucket Shoals. On the other hand, the westerly drift from the Bay of Fundy combines with the active tidal stirring to maintain the low surface temperatures characteristic along the eastern sector of the coast of Maine.

In winter, when the coastal belt is the coldest part of the gulf, the dominant circulation tends to carry low temperatures from the western shores out over the central part of the basin, an effect illustrated by the distribution of temperature in Massachusetts Bay in February, 1925 (p. 658).

THERMAL EFFECTS OF EVAPORATION

The warming of the surface stratum of the gulf by solar radiation is constantly opposed by the draft of heat from the water as the latter evaporates. Quantitative statement of the cooling of the water which this process actually effects over the gulf is not yet possible, but such observations as have been made on the comparitive rapidity of evaporation of salt and fresh waters, and the actual measurements of the latter at land stations around the coast of the gulf, afford a rough picture of the order of magnitudes involved.

The latent heat of vaporization of fresh water depends to some small extent on the temperature at which evaporation takes place; the average for the range prevailing in the surface waters of the gulf of Maine (0° to 20°) is about 585 to 595 calories.[57]

I know of no determinations of the latent heat of evaporation for salt water, but probably it does not differ greatly from the above. The annual evaporation of a blanket of water about 0.7 meters thick from the surface of the Gulf of Maine, which is probably close to the truth (p. 842), would thus take enough heat from the upper 50 meters to cool the latter by about 8° if all the necessary energy were drawn from the water. Actually, however, a large part is supplied by direct solar radiation as it strikes the surface (p. 677), proportionately reducing the draft of heat made from the underlying water by the process of evaporation. No measurements of what percentage of the heat requisite for evaporation is thus supplied direct by the sun seem to have been made at sea, but it is certain that this can happen only while the sun is shining; and evaporation is much more rapid in sunlight than at night or under a cloudy sky—on the average about two and one-half times more rapid, according to Krümmel's (1907, p. 248) summation of the available evidence. The actual hours of sunshine average only about 50 per cent of the possible number at land stations around the gulf, with the sun above the horizon only about half of the time for the year as a whole at our latitude. Thus, a rough approximation of the yearly evaporation from the gulf would be about 0.3 meter (out of the total of 0.7 meter, as stated on p. 842) for the one-fourth of the time when the sun shines on the water, 0.4 meter during the remainder of the year. Without going deeper into this question this implies that the chilling effect of evaporation is certainly sufficient to reduce the mean temperature of the upper 50 meters in the gulf by at least 5° during the course of the year, and probably by at least 6°.

THERMAL EFFECT OF THE NOVA SCOTIAN CURRENT

The distribution of temperature around and in the offing of Cape Sable makes it certain that the cold Nova Scotian drift exerts its chief thermal effect to the eastward of the cape. Nevertheless, it is now fully established that this cold current

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[57] Determinations of the latent heat of evaporation of water vary somewhat. The value stated above is calculated from Herring's formula, $L=94.21\ (365-T)\ 0.31249$. (Quoted from Smithsonian tables, Fowle, 1920.)

floods westward into the Gulf of Maine every spring, in some years into the summer. It is obvious that if this reached the gulf close to zero in temperature, as it is farther east, as well as in large volume, it would effectively cool the eastern side of the gulf just as it cools the coastal zone along outer Nova Scotia, for it is considerably colder than the central part of the gulf even at the season when the latter is at its coldest. This difference in temperature widens during the spring as the vernal warming of the gulf proceeds. Only once (March 29, 1919) have we found this icy Scotian water, 0° in temperature (p. 553) and low in salinity (p. 727), flooding the surface as far west in the gulf as the eastern side of the basin; and, as pointed out (p. 558), the duration of this intrusion of zero water seems to have been brief, because the temperature of this side of the gulf had risen to 2° to 4° by the 28th of April and to 4° to 6° by the end of May (p. 560).

I can not state whether the cold stream from Banquereau brings water as cold as this to the Gulf of Maine every spring. In 1920 it certainly did not do so until after mid April[58] (if at all), when the temperature was still no lower from German Bank and Cape Sable out across the Northern Channel to Browns Bank in the eastern side of the gulf than in the northern and western parts; in fact, slightly higher than in Massachusetts Bay, though the latter is so much farther removed from any possible effect of cold water from the east and north. In 1915 the band of zero water had extended westward past Halifax by the end of May, probably as far west as Shelburne. However, it is unlikely that the Gulf of Maine received any water so cold during that spring; surface readings as high as 3° to 3.5° in the region of German Bank on May 6 to 7 (stations 10270 and 10271) certainly do not suggest this. So sudden a dislocation in temperature had developed by June of that year between the eastern side of the gulf (5° to 8°, surface to bottom) and the coldest band on the Shelburne profile (0.7 to 0.9°, p. 582) that the latter no longer exerted any cooling effect on the temperature to the westward of Cape Sable.

This evidence suggests that while icy water from the Banquereau region (p. 832) reaches the Gulf of Maine as cold as zero for a brief period during some springs, in most years it is so warmed en route by mixture with water of higher temperatures in the neighborhood of Cape Sable that it enters the eastern side of the gulf only a degree or two colder than the water it meets there.

The thermal effect which the Nova Scotian current exerts on the Gulf of Maine is also limited by the fact that it passes Cape Sable as a surface and not a bottom drift (p. 712), its deeper strata being deflected past the Northern Channel and into the so-called "Scotian Eddy" by the obstruction offered to its westward movement by the rising slope of Roseway Bank (p. 836). With the advance of spring the surface of the Nova Scotian current warms, by the sun's rays, as the source of low temperature (ice melting to the eastward) is gradually exhausted, until by July the surface attains a higher temperature all along Nova Scotia (12° to 13°)[59] than around Cape Sable or in the eastern side of the Gulf of Maine, although the bottom water only 20 to 30 meters down continues icy cold. In consequence of this solar warming of the superficial stratum the surface drift that persists from the eastward past Cape

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[58] On the 17th to 19th of that March the coldest water (+0.3° to 0.5°) was then apparently flowing westward between La Have and Roseway Banks at the 20 to 40 meter level.

[59] For summer temperatures over the Scotian shelf see Bjerkan (1919) and Bigelow (1917).

Sable in some summers enters the gulf about as warm as is the contribution from the Cape Sable dead water (p. 835); actually warmer than the water with which it mixes in the offing of Cape Sable or close by to the westward. Although icy cold water persists on bottom right through the summer only a few miles east of the cape, we have no evidence that anything from this source actually penetrates the gulf after May.

In short, the Nova Scotian current acts as a chilling agent in the Gulf of Maine for only a few weeks during the spring, and then more to retard vernal warming (p. 558) than actually to lower the temperature of the part of the gulf into which it debouches below the readings prevailing there before the current commences to flood past Cape Sable. During the short period of its westward flood, however, and for some weeks thereafter, its chilling influence on the eastern side of the gulf is obvious enough, as is described in the account of the distribution of temperature in the spring (p. 553).

We have next to consider how far the difference in temperature between the side of the gulf most directly exposed to the effects of the Nova Scotian current and the opposite side most remote from it is recognizable at other seasons of the year. This problem is complicated by regional differences in the activity of vertical stirring by the tides, reflected in lower and lower surface temperatures at successive stations around the shore line of the gulf from Massachusetts Bay to Nova Scotia, but higher and higher temperatures at the 50 to 100 meter stratum. In order to be instructive for the water mass as a whole, regional comparison must therefore be based on a calculation of the mean temperature of the entire column. To name one part of the gulf as potentially colder than another, or vice versa, on the evidence of temperature of any one given level can only prove misleading.

In calculating the mean temperature the gulf is best divided into two subdivisions—(1) the basin outside the 100-meter contour and (2) the shoaler water of the coastwise zone.

An earlier report (Bigelow, 1915) gives calculations of the mean temperature of the stratum inclosed between the surface and the 50-fathom level for the basin, which would apply closely enough to the upper 100 meters.

Approximate mean temperature (°C.) for the upper 50 fathoms, or 100 meters, of the basin, August, 1913

Locality	Station	Mean temperature	Locality	Station	Mean temperature
Off Gloucester	10087	7.9	Off Penobscot Bay	10091	10.0
Western basin	10086	9.7	Near Cashes Ledge	10090	8.6
North of Cape Ann	10105	8.3	Near central part of basin	10092	8.0
Near Isles of Shoals	10104	8.4	Off Mount Desert	10100	9.1
Off Cape Elizabeth	10103	9.1	Off Bay of Fundy	10097	10.2
Near Platts Bank	10089	8.3	Near Lurcher Shoal	10096	10.1
Off Monhegan Island	10102	9.2	East side of basin	10093	10.0
Off Penobscot Bay	10101	9.4	Do	10094	8.4

According to this table the eastern side of the basin, with the waters along the Nova Scotian slope and off the mouth of the Bay of Fundy, was potentially the warmest part of the gulf (10°), not the coldest, as the popular belief that an

"Arctic current" chills the surface there would demand. This upper stratum was as cold in Massachusetts Bay (farthest removed from the effect of the Nova Scotian current of spring) as it was off Penobscot Bay.

In August, 1914, we again found the mean temperature of the inner part of the basin of the gulf highest in the eastern side near Lurcher Shoal, lowest in the western side off Cape Elizabeth, and slightly higher (7.7° to 9.9°) in the northeastern part in general than in the western (6.8° to 8°), as follows:

Approximate mean temperature (° C.) upper 100 meters, August, 1914

Locality	Station	Mean temperature	Locality	Station	Mean temperature
Off Gloucester	10253	7.7	Off Penobscot Bay	10250	8.8
Off Cape Cod	10256	8.0	South of Mount Desert	10248	8.7
Western basin	10254	7.6	Do	10249	7.7
South of Cashes Ledge	10255	8.6	Off the Bay of Fundy	10246	8.6
Near Isles of Shoals	10252	8.0	Off Lurcher Shoal	10245	9.9
Off Cape Elizabeth	10251	6.8			

Similarly, the mean temperature of the upper 80 meters (the whole column) was as high on German Bank (9.9°), off Machias, Me. (9.7°), and at the western end of the Grand Manan Channel (9.8°) in August, 1912, as it had been off Penobscot Bay or on Platts Bank a week previous (9° to 9.7°), or as it was in Massachusetts Bay two weeks later (about 9.6°). The 80-meter mean was slightly higher off Cape Cod, however (about 11°), on August 29 of that year.

Our data do not afford so satisfactory a regional survey of the mean temperature of the coastwise zone shoaler than 50 to 60 meters because we have taken few observations so close to the land, and it is obvious that regional comparisons for any given stratum within this belt will be misleading unless the observations are made at approximately the same date and at localities where the depth of water is about equal. The few readings that have been taken on Nantucket Shoals show the whole column of water 1° to 2° warmer (mean about 10° to 12°) than in equal depths in the Bay of Fundy (mean 9° to 10°), an instructive comparison because the temperature is kept nearly uniform, vertically, in both these areas by the swirling tides. The mean was also slightly higher over the 50-meter contour in Massachusetts Bay in August, 1922 (11.7° and 13°, stations 10633 and 10640), than we have found it at about this depth off Mount Desert and farther east along the coast of Maine at the same season (usually 9° to 10°); higher, too, than the mean at 35 meters depth in Passamaquoddy Bay in August (10° to 11°), [60] though the difference in depth would suggest a relationship of the opposite sort.

Our summer cruise of 1913 afforded evidence to the same effect, the mean temperature being considerably lower on German Bank (8.7°, station 10095) at the end of the second week of that August than off Cape Elizabeth (about 11° at station 10103). In August, 1914, also, the mean for the upper 50 meters was about 9.7° on German Bank and between 10° and 11° near the Isles of Shoals across the gulf. However, in the cold summer of 1916 (p. 628) the mean for 40 to 45 meters was almost exactly the same at two stations in Passamaquoddy Bay in mid-August (8.5° and 9.4°), in

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[60] Calculated from Craigie's (1916) temperatures.

St. Marys Bay on September 2 (9.8° in 48 meters), and in 40 and 45 meters off Yarmouth Harbor, Nova Scotia, on September 7 and 9[61] (9.2° and 9.8° in 40 and 45 meters) as off Cape Cod on August 29 (9° at station 10398). Much lower summer temperatures prevail to the eastward of Cape Sable, a dislocation illustrated for 1914 by mean values of 10.9° on the northeastern part of Georges Bank and of about 9° on Browns Bank, contrasting with only about 5° at the 50-meter contour off Cape Sable (station 10230) during the last week of July.

These data may be summarized as follows: No definite tendency is shown toward lower mean values for the upper stratum in the one side of the basin of the gulf than in the other, outside the 100-meter contour, in years neither unusually warm nor unusually cold. When we take into account the sharp temperature gradient that characterizes most parts of the Gulf of Maine in summer, as a result of which even slight upwellings from the mid-depths (at, say, 75 to 100 meters) would considerably lower the mean temperature of the shoaler stratum, the most striking result of the calculation is the uniformity of the gulf made evident.

In the coastal belt the mean temperature is usually, though not invariably, a degree or so lower in the northeastern corner of the gulf in summer than in the southwestern side; and it is possible that in years when the movement of water westward along Nova Scotia persists late into the season (1924, for example, p. 834) this regional difference in temperature is wider than has actually been recorded in the summers when our general surveys of the gulf have been carried out. In evaluating it, not only must the possible effect of this cold current be taken into account, but also the difference in latitude between the different stations of observation, which, *per se*, corresponds to some difference in temperature. The most interesting regional comparison which the available records afford from this point of view is between the waters on Nantucket Shoals, on the one hand, and Passamaquoddy Bay, on the other, both being subject to tidal stirring so active that the water remains comparatively homogeneous from surface to bottom throughout the year, and both experiencing about the same amount of fog during the spring and summer.[62] The difference in latitude between these two localities is about 3½°. The mean temperature of the upper 30 to 40 meters of Passamaquoddy Bay is usually between 8.5° and 10.5° in August, when it is at or close to its maximum for the year, differing 1° or 2° in either direction at different stages of the tide and from year to year. On Nantucket Shoals mean temperatures of 10° to 13° have been recorded in summer, so that a difference of about 2° is to be expected between these two regions. According to Krümmel's (1907, pp. 400 and 401) tabulation and diagram this about equals the average difference in surface temperature between the latitudes of the shoals (41°) and of Passamaquoddy Bay (44° 30′), whether for the oceans as a whole or for the North Atlantic alone.

The differences in latitude between Massachusetts Bay (lat. about 42°) and the northeastern shores of the gulf generally (lat. 44° to 44° 30′) corresponds to a difference of between 1° and 2° in mean annual surface temperature for the North Atlantic as a whole.

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[61] Calculated from Vachon's (1918) tables.

[62] According to the pilot chart (United States Hydrographic Office), Nantucket Shoals is somewhat the foggier region of the two in June (40 to 45 per cent of foggy days; 30 to 40 per cent in the Bay of Fundy); but in July about half the days see some fog in the eastern side of the gulf, only 30 to 40 per cent on the shoals.

As every coastwise navigator knows, there is much less fog along the western shore of the gulf from Cape Cod to Cape Elizabeth than there is at the mouth of the Bay of Fundy. Consequently, the former is exposed to more hours of direct sunlight, tending to accentuate the difference in temperature resulting from differences in latidude, *per se.* On the other hand, winds from the quadrant between west and south, such as prevail over the Gulf of Maine during July and August (p. 965), tend to drive the warmed surface water eastward toward Nova Scotia, thus transferring heat from southwest to northeast (with more or less colder water welling up along the western shore), and so in part to counteract the difference in the rate of solar warming which would otherwise accompany the difference of latitude. With a "run" of easterly winds the direction of surface drift will be reversed. Thus, it is by no means a simple task to account for variations in the mean temperature as narrow as those prevailing between different parts of the Gulf of Maine in the summer months. The much wider regional variations in surface temperature or in the temperature of the water at any given level below the surface follow much more obvious causes.

I think it sufficiently established, however, that the difference between the mean temperature of the column of water (in other words, its potential temperature) in the northeastern part of the gulf and in the southwestern part is not greater in most summers than can be accounted for by the difference of latitude and by such other local causes as fog, the direction of the wind, and the regional difference in the activity of the vetical tidal mixing, on which too much stress can hardly be laid.

This is still more certainly the case in winter, when the temperature of the gulf is so nearly uniform, vertically, that station for station comparison of the actual readings at once reveals any regional differences in the mean temperature.

In winter it is only close along shore that any unmistakable difference between the northeastern and southwestern parts of the gulf can be demonstrated, and this is not wider than can be accounted for by the difference in latitude.

Winter temperatures at representative stations during the cold months, ° C.

Locality, date, and station	Surface	40 meters	100 meters
Western side:			
Off Boston Harbor, Dec. 29, 1920, station 10488	3.90	5.34	--------
Off Gloucester, Dec. 29, 1920, station 10489	5.56	6.94	6.97
Off Gloucester, Mar. 1, 1920, station 20050	2.50	1.89	1.52
Eastern side:			
Yarmouth (Nova Scotia) sea buoy, Jan. 4, 1921, station 10501	3.80	3.86	--------
Off Lurcher Shoal, Jan. 4, 1921, station 10500	5.83	6.17	6.70
Off Mount Desert Island, Mar. 3, 1920, station 20056	1.15	.49	1.95

The foregoing discussion leads to the conclusion that the cold water from the Nova Scotian current is soon so thoroughly incorporated with the water of the gulf, after the flow past Cape Sable slackens, that in most years the regional disturbance of temperature which it causes at first is entirely dissipated by June. Even in years when the longshore drift continues to pass Cape Sable until late in the summer (p. 834), it may, at the most, hold the mean temperature a degree or two lower along western Nova Scotia until July than it is out in the neighboring basin of the gulf. After that (earlier still in "early" seasons) the surface water contributed by this source and by the Cape Sable "dead water" (p. 834) reaches the eastern side of the gulf as a warming, not as a chilling, agency, actually 1° to 3° higher in temperature than the water with which it mixes to the westward of Cape Sable.

One more thermal aspect of the Nova Scotian current (this the most important of all) demands brief examination—namely, its more general influence on the temperature of the gulf as distinct from any regional differences which it may cause within the latter. In other words, to what extent is the Nova Scotian current responsible for the boreal character of the gulf? Would the latter be considerably warmer without it?

Until systematic exploration of the gulf was undertaken in 1912 it was generally assumed that the considerable contrast in temperature between the Gulf of Maine, on the one hand, and the tropic water outside the edge of the continent abreast of its mouth, on the other, resulted directly from the chilling effect of some such cold stream from the north and east, though the Labrador and not the Nova Scotian current was usually given this credit. There is no escape from the conclusion that with water at least 3° lower in temperature than that of the gulf flooding into the latter for several weeks every spring, the gulf must be somewhat cooler than it would be if this source of cold should be dammed off.

The older view, that some Arctic current or other controlled the temperature all along the seaboard of the gulf, was largely based on the supposition that the latter is a very cold body of water. It is a truism that the gulf, with a mean annual surface temperature of about 8° to 9°, is considerably colder than the average for its latitude over the oceans as a whole, which is given by Krümmel (1907) as about 14°; so, in fact, is the whole coastal belt along the North American seaboard from Nova Scotia to Florida. However, "cold for its latitude" is by no means synonymous with "cold for its geographic position", and it is more because of its contrast with the tropic waters of the so-called "Gulf Stream" than because of its absolute temperature that the coolness of the Gulf of Maine has impressed students and laity alike. In attempting to estimate whether the gulf is actually colder, and if so, how much colder, than it would be if its offshore banks were to rise above water and so dam it off from currents, warm or cold, the situation of the gulf to leeward of the continent, and the air climate over the land mass from which the chilling winds of winter blow out over the sea, are factors of primary importance. The actual effect which winter chilling by cold air exerts on the temperature of the gulf is discussed in some detail in a later section (p. 692). For clarity, however, I must repeat here that owing to the great difference in capacity for heat between air and water the gulf is but little warmed by warm air blowing over it in summer (drawing its vernal warming almost wholly from direct solar radiation), but is very effectively chilled by the cold air of winter.

If the Nova Scotian current did cool the surface of the gulf generally to a temperature more than a degree or two lower than would result from this winter chilling alone we might expect the mean temperature of the upper 40 meters to prove considerably lower in the eastern side of the gulf than in the western the year round; but by actual observation the difference is no wider in this respect between the parts of the gulf most and least open to the cold current than might be expected to accompany the difference in latitude between the stations in question.

The mean annual temperature of the surface of the gulf affords evidence to the same effect, this being about the same at the mouth of Massachusetts Bay (9 to 10°) as the annual mean for the air at neighboring localities around its shore, or slightly warmer. A similar relationship has been recorded between the mean annual temperature of the surface water of the Bay of Fundy[63] and of the air over the neighboring parts of New Brunswick and of Nova Scotia.

Most instructive clues to the temperatures that might be expected to prevail in the deep strata of the Gulf of Maine if its basin were so nearly inclosed that it could not be affected appreciably by currents from outside are to be found in the relationships between its deep temperatures and those of the Norwegian fjords (Nordgaard, 1903) and of the Black Sea.

In the southwestern Norwegian fjords, where a very heavy rainfall maintains so high a stability that convectional overturnings are confined to the superficial stratum, so that this alone is directly exposed to winter chilling, the bottom temperature is not only uniform throughout the year but is almost precisely the same as the mean annual temperature of the air.[64] So close, in fact, is the correspondence that, Nordgaard tells us, one need only take a reading of the bottom temperature in one of the deep southern fjords to know the mean annual temperature of the air. In the northern fjords, however, which receive so much less rain that the water is less stable, salinity and temperature become nearly equalized from surface to bottom by convectional circulation in winter, just as they do around the coastal belt of the Gulf of Maine, and as a result of this winter chilling causes wide seasonal variations and winter temperatures lower than the mean annual temperature of the air at 200 meters and deeper. In both these classes of fjords, as Nordgaard (1903, p. 46) points out, the bottom temperature is purely the result of local factors, the topography of the bottom being such that "no supply of heat by a submarine current is possible," nor any supply of cold of similiar origin.

More pertinent to the Gulf of Maine is the relationship between the air and water temperatures of the Black Sea, situated at about the same latitude (most of its area is included between the parallels of 41° and 45°), but in a somewhat warmer climatic zone.[65]

At depths greater than 150 to 200 meters the entire area of the Black Sea is 8.8° to 9° the year round (Spindler and Wrangell, 1899; Skvortzov and Nikitin, 1924), contrasting with mean air temperatures for the year of about 9.6° at Odessa, on the north shore, about 11° over the western (Bulgarian) watershed, and about 14.3° at Batum on the eastern coast. That the deeps of the Black Sea should be so much colder than the mean annual temperature of the overlying air, in spite of the warming effect of the bottom current flowing in from the Mediterranean, reflects the age-long effects of winter chilling from above. Obviously the differential can not be credited to any Arctic current in this case.

While no part of the Gulf of Maine is as thoroughly protected from thermal influences from the sea outside as are the Norwegian fjords and the Black Sea, such

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[63] Between 6° and 7° for the year 1916-17, according to Mavor's (1923) tables.

[64] Nordgaard (1903) quotes 7° as the mean annual temperature of the air at Bergen, 6.8° to 7° at 400 meters and deeper in the neighboring fjords.

[65] The Black Sea is usually represented on climatic charts as occupying the belt inclosed between the mean annual isotherms for 10° and 15.56°.

conditions are approximated in the deep bowl off Gloucester. By analogy, therefore, we might expect the mean annual temperature of the bottom water of the latter to be lower than the mean annual temperature of the air over the neighboring land, quite independent of any possible chilling by northern sources. And such, by our observations, is the case, the mean bottom temperature of 4° to 5° at 70 to 150 meters depth in this sink being 3° to 4° below the mean annual temperature of the air at Plymouth and Gloucester, on the two sides of the bay, or at Concord, Mass., some 20 miles inland.[66] We have not taken readings enough in the deep trough between Jeffreys Ledge and the Isle of Shoals to establish the mean annual temperature as closely there, but such data as are available point to a mean annual value of 4° to 5° at 100 to 150 meters for this locality, about 3° lower than the mean annual air temperature at Portland, Me. (7.3°).

Near Mount Desert Island, which may be taken as representative of the coastal waters of eastern Maine, the mean annual temperature of the bottom water (close to 5° to 6° at a depth of 40 to 50 meters) is about 1° cooler than the mean temperature of the air at Bar Harbor near by, but nearly the same as the air at St. Johns, New Brunswick, and at Eastport, Me. Mean temperatures of 4° to 5° at depths of 100 to 175 meters in the Bay of Fundy for the year November, 1916, to November, 1917,[67] again prove 1° or 2° lower than the mean annual temperature of the air at St. Johns, New Brunswick, on the one side of the Bay, or at Yarmouth, Nova Scotia, on the other (5° to 6°).

The foregoing comparison warrants the tentative generalization that in those parts where regional interchange of water is most hindered by submarine barriers the mean temperature of the bottom water averages about 1° to 3° lower than the mean annual temperature of the air over the neighboring lands, a rule applying whether vertical circulation be active, as in the Bay of Fundy, or weak, as off Gloucester. The mean annual bottom temperature at equal depths also proves decidedly uniform in such situations in the two sides of the gulf. In the open basin of the gulf the deepest water averages warmer, a fact discussed in a subsequent section (p. 691). In short, it is not necessary to invoke more than a slight influence on the part of the Nova Scotian current, if any, to account for thermal differences between bottom water and air no wider than those just quoted.

Brief analysis will, I think, convince the reader that this conclusion applies equally to the cold mid layer that usually persists through the summer in the basin of the gulf. The presence of a cold layer of water of this sort in the mid depths, with higher temperatures below as well as above it, has sometimes been classed as a sure criterion for Arctic water. This, however, is not necessarily the case. True, such a state characterizes the polar seas in summer (Nansen, 1902; Helland-Hansen and Nansen, 1909; Knudsen, 1899; Matthews, 1914); and wherever such a layer is colder than −1° in summer, as it is in the Labrador current and in the extensions of the latter around the slopes of the Grand Banks (Matthews, 1914; Fries, 1922 and 1923; E. H. Smith 1922 to 1924a; Le Danois, 1924 and 1924a) we have positive evidence of Arctic water, for nowhere else does winter cooling alone cause temperatures as low as this in the open sea on either side of the North Atlantic south of latitude 60°.

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[66] The mean annual temperature is higher (about 10°) at Boston than at most other stations around the bay.

[67] Calculated from data tabulated by Mavor (1923).

However, a cold layer of this same sort, though not so low in temperature, can equally be produced in any partially inclosed boreal sea. All that is requisite is that the surface layers be exposed to a rigorous winter climate, alternating with rapid solar warming in summer, over depths great enough to allow a more or less constant inflow of warmer ocean water below the level to which winter cooling penetrates (Bigelow, 1917, p. 237).

In the Baltic, for example, a cold layer reminiscent of the previous winter's chilling persists at a depth of 50 to 100 meters until well into the summer (Knudsen, 1909; Krümmel, 1907, p. 471; Witting, 1906); but increasingly active vertical circulation, which accompanies the cooling of the surface after August, entirely dissipates this stratum of low temperature there by late autumn, just as happens in the Gulf of Maine. The following serial temperatures for the Alland Deep (in the Baltic) in winter, spring, summer, and autumn, are introduced for comparison with the Gulf of Maine.[68]

Depth	February	May	August	November
	°C.	°C.	°C.	°C.
Surface	0.1	4.2	12.3	6.1
100 meters	2.4	1.8	2.5	5.3
250 meters	3.9	2.0	3.5	4.0

A cold mid layer of the same sort persists into the summer in the Black Sea, where it is self-evident that cold Arctic currents play no part in the temperature cycle and where, consequently, the low temperatures recorded at 60 to 100 meters in August must be purely the product of local influences, as Andrusoff (1893) has pointed out.

With melting ice no more important in the Black Sea than it is in the Gulf of Maine,[69] the cooling agent chiefly responsible must be the loss of heat from the surface by radiation during the cold months.

The general account of temperature, and especially the temperature sections for the western basin in successive months (fig. 5), makes it clear that the cold layer recorded in summer in the Gulf of Maine reflects the persistence of the low temperature to which the whole upper 100 to 150 meters is chilled in winter, but which is obliterated by autumn, just as happens in the Baltic. No connection appears on the profiles between the development of this cold layer in the western side of the gulf as the spring advances, and the inrush of Nova Scotian water into the eastern side.[70]

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[68] From Krümmel (1907, p. 471), after Witting (1906).

[69] The northwestern bays and harbors of the Black Sea (e. g., Odessa Gulf and Kherson Bay) usually freeze over part of the time each winter; but ice very seldom extends more than 2 or 3 miles seaward, and even these shallow areas of low salinity are sometimes open all winter, while the open sea south of the Crimean peninsula never freezes (British Admiralty, 1897). Consequently the amount of ice that actually melts in the Black Sea proper each spring is so small that we can hardly suppose it has any appreciable effect on sea temperature there.

[70] In an earlier report (Bigelow, 1917) I referred to the Gulf of St. Lawrence as a thermal example of this same sort; but Huntsman's (1924 and 1925) more recent hydrographic studies indicate a greater inflow of icy water from the Labrador current through the Straits of Belle Isle than Dawson's (1907 and 1913) earlier observations of the strait had suggested. Consequently, the persistence into the summer of the minimum layer there, close to 0° in temperature at about 100 meters' depth, results at least in part from the cold water flowing in and from the melting of the Arctic ice which this brings with it in winter and early spring, as well as from winter chilling and the melting of ice frozen locally within the Gulf of St. Lawrence.

The evidence just outlined leads to the conclusion that the Nova Scotian water flowing into the Gulf of Maine from the eastward in spring does not lower the general temperature of even the coldest localities and levels in the gulf more than a degree or two below the values that would prevail were the gulf as nearly inclosed as are the Black Sea or the Norwegian fjords. Nevertheless, the Nova Scotian current does act as a decidedly effective cooling agent, for without the cold water from this source the comparatively high temperature of the slope water, of the surface inflows from the region off Browns Bank, and of occasional overflows of tropic water (p. 836), would hold the gulf several degrees warmer than it actually is. These warm sources the Nova Scotian current counteracts, and in counteracting them it has its chief thermal importance in the Gulf of Maine.

THERMAL EFFECT OF THE SLOPE WATER

Were the gulf an inclosed basin, with little or no inflow over its floor, we should expect to find its bottom temperature certainly no higher then 5° to 6° and probably as cold as the mean annual temperature actually is in the deep sinks in the western side of the gulf, namely 4° to 5° (p. 688). In reality, however, we have only once found the bottom water in the basin of the gulf colder than 4° in depths of 175 meters, or deeper, at any locality, season, or year.[71] Only 4 out of 64 deep stations in the basin have given bottom readings lower than 4.5°. On the other hand, 26 have been warmer than 6° on bottom; and the bottom temperature for all as deep as 175 meters has averaged about 6°, or 1½° warmer than the mean annual temperature at the 100-meter level around the shores of the gulf and 2° warmer than the mean bottom temperature in the trough of the Bay of Fundy. The high salinity, coupled with the precise temperature of this bottom water, identifies it beyond dispute as slope water flowing in along the trough of the Eastern Channel (see discussion p. 842). The slope water, then, brings warmth to the deeps of the gulf sufficient to raise the bottom temperature of the basin a degree or two higher than would be the case if no such current flowed in; consequently it must be named a warm current as it affects the gulf, not a cold one.

The physical characteristics of the slope water, as it drifts inward along the bottom of the Eastern Channel, have proved so uniform from season to season and from year to year (temperature about 6° to 7° and salinity about 34.6° to 35° per mille in spring and summer) that the causes for the variations recorded in the temperature and salinity of the deepest water within the gulf are to be sought in fluctuations in the volume and velocity of the inflowing bottom drift rather than in variations in the temperature or salinity of the latter. Such fluctuations, in turn, almost certainly have a two-fold cause. In part they result from corresponding variations in the amount of slope water being manufactured along the continental slope to the eastward shortly prior to the date of observation, and in the proportional amounts of the various waters, cold and warm, that enter into its composition. The seasonal or or other secular differences in the density gradient over the continental slope from Browns Bank to La Have Bank, however, probably play a more important rôle in

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[71] Bottom temperature 3.54° at 180 meters at station 10283 off the Bay of Fundy, June 10, 1915.

this connection by governing the Archimedian force that tends to pump the slope water westward to the Eastern Channel and so into the Gulf of Maine. This works most effectively in spring and early summer, but fluctuates so narrowly from season to season that only very narrow variations are to be expected in the temperature or salinity of any part of the gulf deeper than about 150 meters, from season to season or from year to year, or have actually been recorded there.

This uniformity in the physical state of the bottom water on the floor of the deep trough of the gulf proves that the effects of the alternate seasonal warming and chilling of the surface do not penetrate deep enough to obscure the dominance of the slope water there; but the slight seasonal rise and fall of temperature that has been recorded at the bottom of the deep sink off Gloucester and between Jeffreys Ledge and the mainland (from which the slope water is barred by inclosing rims too shoal for it to overflow) is evidence that slight (but measureable) winter cooling and summer warming from above may be detected down to 200 meters, so far as the depth alone is concerned.

It is because the slope water is warm, by comparison with the water with which it mixes within the gulf, that the bottom of the latter is usually warmest in the eastern side of the basin, at depths greater than 150 meters, where the inflowing current is chiefly localized (p. 921), coldest in the "sinks" in the inner parts of the gulf, from which the slope water is more or less effectually barred by submarine rims.

The following differential table shows that the slope water has little effect on the deep temperature in such situations, as exemplified by the sink off Gloucester and by the trough between Jeffreys Ledge and the Isles of Shoals. This generalization applies also to the Bay of Fundy, from which most of the slope water is deflected by the topography of the bottom. In summer and autumn, it is true, the 175 to 200 meter level may be as warm within the bay (6° to 7°) as without; but low salinity proves that this high bottom temperature chiefly reflects the active convectional currents of the bay by which solar heat received at the surface is dispersed more evenly downward there than it is anywhere else in the gulf in water equally deep.

Depth, meters	Cape Ann bowl, deepest level taken			Basin outside, corresponding level[1]		
	Date	Station	Temperature	Date	Station	Temperature
			°C.			°C.
150	Mar. 1, 1920	20050	1.68	Feb. 23, 1920	20049	5.66
150	Apr. 9, 1920	20090	(2)	Apr. 18, 1920	20115	5.38
120	do	20090	2.25	do	20115	±3.80
130	May 4, 1915	10266	3.55	May 5, 1915	10267	4.69
110	July 10, 1912	10002	4.61	July 15, 1912	10007	±4.61
128	Aug. 9, 1913	10087	5.17	Aug. 9, 1913	10088	[3]±5.50
180				do	10088	6.28
140	Aug. 22, 1914	10253	4.49	Aug. 22, 1913	10254	±5.30
140	Aug. 31, 1915	10306	5.78	Aug. 31, 1915	10307	±5.10
120	Oct. 31, 1916	10399	5.23	Nov. 1, 1916	10400	±4.40
150	Dec. 29, 1920	10489	7.00	Dec. 29, 1920	10490	±6.00

[1] The table shows only the differential existing on the given dates between the deepest level, where a reading was taken within the bowl, and the corresponding level in the basin outside. It does not represent the seasonal cycle for the latter because of the difference in levels from station to station.

[2] 150-meter reading not taken.

[3] 130 meters.

Further evidence that slope water is of little importance in the thermal cycle of the Bay of Fundy results from the fact that we found the 200-meter level 1° colder (4.3°) within the latter than just outside (5.4°) in March, 1920 (stations 20079 and 20081), with a corresponding difference in salinity. A reading of 1.71° reported by Mavor (1923) at 175 meters in the bay on April 9, 1917, is colder than the coldest reading so far obtained anywhere in the open basin of the gulf at this depth.

The deep readings for different times of year warrant the following generalizations: At depths greater than 150 meters the temperature is most nearly uniform through the year in those parts of the gulf which the slope water reaches in greatest volume, and shows its widest seasonal fluctuation in the partially inclosed bowls that receive least water from this source. Were it not for this deep current flowing in, the floor of the gulf would be several degrees (perhaps 3° to 4°) cooler in winter than is actually the case, and its mean for the year slightly lower. The bowl off Gloucester and the trough west of Jeffreys Ledge show the nearest approach to the thermal state that would prevail in the gulf were it neither open to the inflowing bottom current nor stirred by such strong tides as those that disturb its eastern side.

The thickness of the bottom stratum where temperature is governed by the volume and precise physical characters of the slope water is of interest. Its upper boundary in the inner part of the basin of the gulf may be set tentatively at about the 150-meter level, rising to within 80 to 100 meters of the surface in the southeastern part at the entrance to the Eastern Channel. On the other hand, the deep temperature is most influenced from above where tidal or other convectional stirring is most active.

WINTER CHILLING

Abyssal upwelling, as I have shown (p. 853), is barred out as a possible source of autumnal cooling in the Gulf of Maine. It is equally certain that the Nova Scotian current usually serves as a cooling agent in the gulf only in the spring, because none of our observations for autumn or winter suggest that progression of cooling from east to west across the gulf, which would reflect any inflow of cold water past Cape Sable at that season. We must therefore credit the very rapid loss of heat which the Gulf of Maine suffers in autumn and winter entirely to local causes, chiefly to the radiation of heat out from the surface to and through the colder air above it; to evaporation; in less degree to the melting of the snow that falls on the sea; and, locally, to the melting of ice.

The warming effect of the sun's rays is combatted the year round by local influences tending to reduce the temperature of the water or as least to retard vernal warming. Evaporation from the surface, for one thing, uses up heat, thus cooling the water (p. 680). Furthermore, the heated surface radiates heat out into the air whenever the temperature of the latter drops below that of the water, even in spring and summer.

The solar energy absorbed by the water is more than enough to offset these forces up to mid or late August; consequently the temperature of the surface of all parts of the gulf continues to rise. However, the amount of solar heat daily absorbed by the water, at its maximum when the sun is at its highest declination, is constantly decreasing after June 22 to 23; and after a certain date toward the end of summer or early in autumn, a date that varies regionally, as described in an earlier chapter

(p. 636), the surface chills. At first this chilling chiefly reflects the convectional mixing of the upper stratum, by which the substratum is warmed, in proportion as the surface is cooled, combined with the effects of evaporation from the surface. Meantime the mean temperature of the whole column of water continues to rise slowly at first, then remains stationary for a time as the sun continues to lose strength. At the mouth of Massachusetts Bay, for example, the mean temperature of the upper 40 meters was slightly higher on August 31, 1912 (station 10045, about 12°), than it had been on July 10 (station 10002, about 11°), although the surface had cooled from 18.3° to 16.1° in the interval. In 1915, too, the mean temperature of the upper 100 meters remained virtually unaltered at the mouth of the bay from August 31 to October 1 (about 8° at stations 10306 and 10324), although the surface temperature fell from 16.1° on the first date to 10.3° on the second, and the mean temperature of the upper 40 meters from 11° to 9°. In fact, it is doubtful whether the column of water, as a whole, actually commenced to lose heat at the mouth of the bay before the end of that October (p. 638). In 1916, again, the mean for 80 meters was about 1° higher near Cape Cod on October 31 (station 10399, about 7°) than it had been at the mouth of the bay near by on July 19 (station 10341, about 6°), the 80-meter temperature having risen in the meantime from about 3.7° to about 5.8°, though the surface reading had fallen from 16.4° to 10°.

Thus, the heat received from the sun is sufficient to balance the loss of heat by evaporation and by radiation at night, when the temperature of the air is cooler than the water, until the date when the mean temperature of the air falls permanently below that of the water, so to continue through the autumn and winter. Thereafter the upper 100-meter stratum of water constantly loses heat, no longer merely simulating this loss by convectional equalization. As this loss of heat is chiefly the result of radiation, out from the water into the air, the efficacy of this process deserves a word.

Although warm winds, as we have seen, heat the water below them to only a small degree, and slowly, because of the very much higher capacity of the latter for heat, cold winds, on the contrary, chill the surface of any body of water, fresh or salt, very rapidly because dry air is extremely transparent to radiation, especially to the long wave lengths (Abbott, 1911; Hann, 1915). Because of this "diathermacy," and because water is a good radiator,[72] the surface radiates out very large amounts of heat from September on, whenever the air is cooler than the water, dry, and the sky clear of clouds, fog, or mist, very little of it being absorbed by the lower stratum of the air.

The greater the difference in temperature between the air and the water, and the drier the air, the more rapidly does the water lose heat in this way. When the air is damp, or the sky clouded, the radiation from the surface of the sea is intercepted by this water vapor, so that the water loses heat slowly under such circumstances even if the temperature of the air be considerably the lower. It happens, however, that the humidity rules low and the sky usually is clear during the coldest winter weather of New England and of the Maritime Provinces, especially at night. Consequently, other conditions most favor radiation just when the differential

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[72] Schmidt (1915) found about 83 per cent as much radiation from a water surface as from a black surface.

between sea and air temperature is widest, as it is from November on through the winter over the Gulf of Maine (p. 671).

Water itself is so opaque to radiation that only the thin surface film that is actually in contact with the air loses heat rapidly when the air is the colder of the two, for it effectually insulates the deeper strata. Consequently, the rate of radiation from water to air depends on the activity of vertical circulation; the more actively the water is stirred by tides or waves, and the more constantly the surface layer is replaced by water from below, the more rapidly will the column give off its heat to the colder air and so cool off with the advance of autumn and winter.[73] For this reason it would be reasonable to expect the gulf to reflect the autumnal cooling of the air most closely where tidal stirring is most active, and temperatures taken by Vachon (1918) in the St. Andrews region in 1916 prove this to be the case.

The coldest winter winds of the region blow from the land out over the gulf, and these cold westerly winds predominate in the western side of the gulf during the three winter months (p. 965). Consequently, the water loses heat most rapidly in the coastwise belt around the western and northern shore of the gulf, over which a fresh supply of icy air from the land is constantly passing, as long as the cold winds blow from the quadrant between north and west. The wind, in turn, is warmed by the absorption of radiant heat from the surface of the water in its passage over the latter; for although the lower stratum of air absorbs but a trifling percentage of this total radiation, its capacity for heat is so low that but little heat need be intercepted by it to raise its temperature considerably. This interception is favored, furthermore, by the increasing humidity given the air by the evaporation that is constantly taking place from the surface of the water. The result is that by the time the air has traveled a certain distance out from the land, its temperature rises so close to that of the water, and the air is made so humid, that the sea loses heat by radiation but little faster than it gains heat from the sun, even in midwinter.

In any sea exposed to a rigorous air climate, winter chilling may be expected to proceed much more rapidly in inclosed harbors, among the islands, and close in to the land generally, than it does only a few miles out at sea. This general rule is exemplified in a typical way by the Gulf of Maine, where the stations closest to the land have proved considerably the coldest in late autumn, winter, and early spring. The thermal history of Massachusetts Bay during the winter of 1924–25 affords a good example of this.

Storm winds also hasten the winter chilling of the water by the stirring action exercised by the waves, which may reach down to very considerable depths at this season, when the water has little vertical stability. In severe winter storms the whole upper stratum, 100 meters thick, may be mixed in this way and a constant supply of new water thus brought up to the surface, there to give off its heat to the icy air.

Were vertical stirring not so active in autumn, the immediate surface would cool off even more rapidly than it actually does, and the whole coastwise belt of the gulf, if not the entire area, would freeze over in winter. At the same time, however, the surface film would interpose so effective a barrier to the radiation of heat upward

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[73] See Nansen (1912) for an illuminating discussion of the loss of heat from the surface of the Northern Atlantic in winter, and on the extent to which this is governed by the freedom of vertical circulation.

from the deeper strata, by its opacity to this process (p. 694), that the water only a meter or two down would lose heat much less rapidly than happens in reality, so that the 20 to 30 meter level probably would not show enough cooling during the winter months for the change in temperature to be measurable on our ordinary deep-sea thermometers.

Actually, however, vertical circulation is most active during the cold half of the year; consequently, the mixing of the various strata of water is constantly bringing up fresh water from below, to radiate its heat out into the atmosphere. The fact that the upper 100 meters, or so, cools off so uniformly during the winter, instead of only a thin surface film, is therefore wholly the result of convectional movements of the water particles, induced either mechanically (by winds or tides) or dynamically, if the surface water so chills that it becomes heavier than the underlying layer, which, however, seems never to take place in the open gulf (p. 929).

The rigorous climate of northern New England and of the Canadian Province of New Brunswick so profoundly influences the sea temperature of the Gulf of Maine that the following tables of the air temperatures at stations bordering the gulf may be of interest.[74]

Normal air temperatures (Fahrenheit)

Locality	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Boston	27.0	28.0	34.5	45.3	56.6	65.8	71.3	68.9	62.7	52.3	41.2	31.6
Portland	22.0	23.8	32.0	43.0	53.5	62.6	68.0	66.2	54.2	49.1	37.6	27.1
Eastport	20.1	20.4	28.9	38.3	46.9	54.4	59.8	59.7	55.2	46.6	36.8	25.3

Mean winter temperatures °F, with departures from normal (J. W. Smith, 1913–1921)

Locality	December		January		February		March	
	Temperature	Departure	Temperature	Departure	Temperature	Departure	Temperature	Departure
1911-12								
Boston			21.4	−5.6	27.7	−0.3	36.0	+1.0
Portland			15.3	−6.7	28.2	− .6	30.2	−1.8
Eastport			14.3	−5.8	20.4	−1.0	28.8	− .1
1912-13								
Boston	38.5	+6.9	39.3	+12.3	27.7	−0.3	42.4	+7.4
Portland	32.3	+5.2	31.6	+ 9.6	21.0	−2.8	35.2	+3.2
Eastport	28.7	+3.4	27.8	+ 7.7	17.2	−4.2	32.0	+3.1
1914-15								
Boston	30.4	−1.2	33.0	+6.0	33.2	+5.2	35.8	+0.08
Portland	24.4	−2.7	26.4	+4.4	28.4	+4.6	32.2	+ .02
Eastport	23.6	−1.7	24.6	+5.5	27.6	+6.2	29.9	−1.00

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[74] From the U. S. Weather Bureau.

Mean winter temperatures °F, with departures from normal (J. W. Smith, 1913–1921)—Continued

				1915–16				
Boston	34.2	+2.6	33.0	+6.0	25.5	−2.5	30.6	−4.4
Portland	29.4	+2.3	26.6	+4.6	20.6	−3.2	26.8	−3.2
Eastport	29.6	+4.3	22.6	+2.5	19.3	−2.1	24.6	−4.3
				1919–20				
Boston	28.8	−2.8	21.0	−0.6	27.6	−0.4	39.2	+4.2
Portland	22.8	−4.3	14.6	−7.4	22.2	−1.6	34.6	+2.6
Eastport	20.0	−5.3	11.5	−8.6	21.1	−0.3	30.4	+1.5
				1920–21				
Boston	35.6	+4.0	-----	-----	-----	-----	-----	-----
Portland	27.8	+0.7	-----	-----	-----	-----	-----	-----
Eastport	27.5	+2.2	-----	-----	-----	-----	-----	-----

The diagrams of air and surface temperature at Gloucester and at Boothbay for the winter of 1919–20 (figs. 29 and 30) show the temperature of the water closely following that of the air in its 10-day fluctuations, and reflecting a loss of heat by radiation more or less rapid as the difference between the temperature of air and water is greater or less.[75]

The loss of heat from the surface of the gulf increases proportionately from November on, as the average difference between air and water increases, a general rule illustrated by the temperature cycle of Massachusetts Bay for the winter of 1924–25 (p. 651). The water continues to suffer a net loss of heat in this way until the average temperature of the air once more rises above that of the water, an event to be expected about the tenth of March (p. 668).

CHILLING EFFECT OF MELTING SNOW

Another cooling agent becomes effective from December until spring—namely, the melting of the snow that falls on the surface of the gulf. The amount of heat taken from the water by melting snow is, of course, that required to melt an equivalent amount of ice; a fall of 1 foot of snow (a moderate snowstorm for northern New England and the Maritime Provinces) would represent approximately 1–1½ inches of ice, more or less according to the quality of the snow.

The normal snowfall, by months, for the lands bounding the gulf is tabulated below from data supplied by the United States Weather Bureau; also the actual snowfall for representative winters since the oceanographic investigation of the gulf was undertaken.

Normal snowfall and its equivalent in water, both given in inches

Locality	November		December		January		February		March		April	
	Snow	Equivalent water	Snow	Equivalent water	Snow	Equivalent water	Snow	Equivalent water	Snow	Equivalent water	Snow	Equivalent water
Boston	0.6	0.08	5.8	0.55	9.7	0.87	13.7	1.23	9.0	0.87	3.7	0.46
Portland	3.6	.64	10.8	1.70	16.0	2.32	20.0	3.02	11.7	1.82	4.2	.78
Eastport	3.4	.40	11.7	1.26	17.6	1.72	19.7	1.90	13.3	1.28	10.1	1.04
Yarmouth, Nova Scotia	4.0	.40	14.4	1.47	20.3	2.03	21.8	2.18	13.3	1.30	5.5	.50

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[75] The air temperature of the coldest days was many degrees below the 10-day averages shown on the diagrams, often 10° colder than the surface of the water.

Snowfall, in inches

Locality	November	December	January	February	March	April
WINTER, 1912–13						
Boston	0.3	9.2	0.3	7.7	0.5	1.4
Portland	(1)	4.7	5.0	14.1	5.1	1.2
Eastport	2.0	6.9	7.9	14.6	9.3	3.7
Yarmouth, Nova Scotia	12.2	7.7	1.2	16.3	3.5	1.1
WINTER, 1914–15						
Boston	(1)	4.1	7.0	5.1	(1)	----------
Portland	7.4	8.1	1.9	10.5	0.8	----------
Eastport	4.5	9.0	12.2	10.3	4.8	----------
Yarmouth, Nova Scotia	4.1	15.3	10.2	7.2	2.5	----------
WINTER, 1915–16						
Boston	0.2	6.7	4.8	30.3	33.0	6.5
Portland	(1)	12.1	12.2	20.2	36.3	7.9
Eastport	(1)	4.4	14.0	21.8	14.7	4.2
Yarmouth, Nova Scotia	3.0	6.1	21.3	29.4	53.4	1.7
WINTER, 1919–20						
Boston	0.2	2.9	24.8	32.5	11.0	2.0
Portland	2.7	4.3	24.2	44.6	13.6	0.3
Eastport	1.9	16.9	20.2	37.2	14.2	13.7
Yarmouth, Nova Scotia	2.4	13.6	28.0	15.2	3.7	8.0

[1] Trace

On the average, the coastwise belt of the gulf annually receives a blanket of snow aggregating about 42 inches in thickness off Boston, 66 inches at Portland, 76 inches off Eastport, and 79 inches at Yarmouth, Nova Scotia. Translated roughly into terms of ice, this means 4.5, 11, 8.5, and 9 inches, respectively, or an equivalent of about 8 inches of ice as the mean for the coastwise belt from the land out about to the 25-meter contour. Farther out from the shore a larger proportion of the winter's precipitation comes down as rain, less as snow, but no measurements of the snowfall have been made at any offshore station in the gulf.

As to melt 1 kilogram of ordinary fresh-water ice requires heat enough to raise the temperature of 75 to 80 kilograms of water by 1°,[76] melting 8 inches of ice will take heat enough from the water to cool a stratum 12 to 14 meters thick by about 1°; and probably this is a fair measure of the average cooling effect of snow falling on the coastwise belt of the Gulf of Maine within 5 to 10 miles of the land.

CHILLING EFFECT OF MELTING ICE

The melting of floating ice in high northern and high southern latitudes exerts a potent effect upon the distribution of temperature[77] in the North Atlantic; and the melting of ice, whether frozen locally or of Arctic origin (p. 689), is the most potent

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[76] Recent measurements place the latent heat of fresh-water ice between 75 and 80.3 calories. (Krümmel, 1907, p. 507.)

[77] Salt-water ice is less effective as a cooling agent than fresh-water ice (floe ice, that is, than berg ice), because its latent heat of melting is somewhat lower. Petterson (1888) gives this as approximately 52 to 53 calories for ice frozen from water of about the salinity of the Gulf Maine.

factor in producing the low temperature of the mid-layer of the Gulf of St. Lawrence.

The chilling effect of ice melting in the Gulf of St. Lawrence, and to a greater extent of the drift ice melting over the Banquereau–Sable Island Bank region is, in turn, brought indirectly to the Gulf of Maine by the cold water flowing westward past Cape Sable in spring and early summer (p. 832); but no ice, either of Arctic or of St. Lawrence origin, has ever been known actually to enter the Gulf of Maine though pans (almost certainly from the latter source) do rarely drift down past Cape Sable along the edge of the continent or outside it. Consequently, as the surface of the open Gulf of Maine never freezes, ice melting *in situ* plays only a very subordinate role in its temperature complex, except in its shallow and more or less inclosed bays and among the islands that skirt its northern shores.

Cape Cod Bay offers an instructive example, on a small scale, of the effect that melting ice exerts upon the sea temperature, for more or less ice freezes over the flats along its western side nearly every winter. The greatest amount forms during heavy blows from the northwest, when it may stretch out 2 or 3 miles from the shore and pack several feet high along the beach. When ice has so formed, easterly winds and high tides soon disperse it; and, according to the United States Coast Pilot (1912, Part III, p. 59), "instances are on record of this ice, and that forming in the shallower parts of Cape Cod Bay in severe winters, being driven by the winds out into the bay, where it masses into heavy fields or windrows, sometimes as much as 10 feet or more thick, making the navigation of parts of the bay unsafe or impracticable at times."

Unfortunately, no observations were taken in Cape Cod Bay during the ice season of the almost Arctic winter of 1919–20, or until April of the succeeding spring; but in 1924 a considerable amount of ice formed along the west shore of the bay between the 20th and 26th of December, during a spell of very severe weather (p. 655), and the temperatures taken by the *Fish Hawk* on January 6 and 7, 1925, showed the effect by a drop in temperature at the near-by station (No. 7) from about 4.3°, two weeks previous, to about 0.3°. Ice chilling was also reflected still more clearly in the fact that the water was colder just off Wellfleet Bay (station 7) than anywhere else in the southern part of the Massachusetts Bay region on that date, as is described above (p. 655).

The sea ice that freezes in greater or less amount among the islands along the coast of Maine in all but the warmest winters must also exert a local chilling effect on the water as it melts, but no measurements of this have yet been made.

In severe winters, when much ice forms in Vineyard Sound, most of it reported to drift out to the eastward past Nantucket, melting ice must lower the temperature of the Nantucket Shoals region indirectly or directly. Here, again, however, definite data are lacking.

Ice is also an effective chilling agent in shallow bays such as Barnstable and Plymouth, for the flats, laid bare at low tide, skim over with ice on cold winter days or nights, which melts when the tide floods again. This is one reason (active tidal circulation is another) why such situations serve as centers for chilling in winter, just as they do as centers for warming in summer.

THERMAL EFFECT OF THE RIVER WATER

The great volume of river water that pours into the gulf every spring, at a temperature only a few degrees above the freezing point, when the ice goes out of the lakes and the snow melts, must tend at first to delay the vernal warming of the gulf. However, no attempt has yet been made to estimate its actual effect.

SUMMARY OF THERMAL DETERMINANTS

The interaction of the several major factors that govern the temperature of the gulf is so complex that a summary of them may be useful.

It is definitely established that the gulf owes the particular temperatures proper to it, and especially the wide seasonal range of temperature, chiefly to its geographic location to leeward of the continent and to the rigorous land climate. Only in a much smaller degree is it influenced by warm or cold currents flowing into it.

Our successive cruises and the observations taken in the Bay of Fundy by the Biological Board of Canada, therefore, corroborate the view long ago advanced by Verrill (1874) that the waters of the Gulf of Maine are not abnormally cold, considering their geographic location and the rigorous climate of the neighboring land mass; that, in short, to describe its temperature as "Arctic," as has so often been done, is entirely a misnomer.

The chief source of warmth for the superficial stratum of the gulf is the solar heat absorbed by the water *in situ*. Vernal warming is therefore chiefly of local origin. The rapidity with which solar heat is dispersed downward in the water and the depth to which it penetrates depend on the activity of vertical circulation, whether by tides, winds, storm waves, or dynamic overturnings; and the regional differences in the temperature gradient, which develop in the gulf in summer (Massachusetts Bay at the one extreme, the Bay of Fundy and Nantucket Shoals at the other), result chiefly from differences in the thoroughness with which the tides churn the water.

The low surface temperature that prevails along the eastern coast of Maine and in the Bay of Fundy in summer, as contrasted with the Massachusetts Bay region, is chiefly due, therefore, to local causes and not to the "Arctic current" that has so commonly been invoked to account for it.

The surface stratum of the gulf likewise receives heat from warm winds blowing over its surface, from surface water drifting into its eastern side from the region of Browns Bank and the Cape Sable dead water, and also, at long intervals, from overflows from the tropic water outside the edge of the continent.

Vernal warming is opposed by the Nova Scotian current flowing from the eastward, past Cape Sable, into the gulf. During the brief period when at its maximum, this current may lower the surface temperature by a couple of degrees right across to the western side of the basin, thus temporarily producing a regional differentiation; and it considerably delays vernal warming in the eastern side probably every year. However, this cold drift is so thoroughly incorporated into the water of the gulf soon after the actual flow past the cape slackens that no regional differentiation from this source can be traced definitely in the gulf after midsummer. Neither is its general temperature made more than 2° to 3° lower than would be the case if the gulf were entirely barred to currents, cold or warm; but the chilling effect of the Nova Scotian current is more important than this bald statement suggests, for it counteracts, by several degrees, the effect of the warm sources just mentioned.

Autumnal and winter chilling, so conspicuous a feature of the gulf, results primarily from the loss of heat from the surface by radiation, after the date when the mean temperature of the air falls below that of the water; neither cold currents from the north nor upwelling from the oceanic abyss have any major part in it.

Snow falling and melting on the surface is also a cooling agency of some efficacy; so, locally, is melting ice in Cape Cod Bay and among the islands along the coast of Maine. River drainage, by its low temperature in early spring, also tends to retard vernal warming. Evaporation from the surface also tends to chill the water throughout the year, accounting for a probable cooling of the mean temperature of the upper 50 meters by 5° to 6°.

The temperature of the superficial 100 meters of water is governed chiefly by these climatic (including solar) influences from above, by the thermal effect of the inflows into the eastern side of the gulf, and by the chilling effect of evaporation from the surface.

The cold layer that persists in the basin throughout the summer at a depth of 100 to 150 meters in most years is simply reminiscent of the lowest temperature to which this level chilled during the preceeding winter—not of an Arctic current. This layer is colder than the deeper water in most summers because the temperature of the latter is determined chiefly, not by seasonal climatic influences, but by the volume of the warmer slope water flowing in through the eastern channel, and by the course that this current follows inward along the two branches of the trough of the gulf. If the inflow of slope water is smaller than usual, or cooler, the summer temperature of the inner part of the basin is virtually uniform, vertically, from about 100 to 150 meters down to the bottom, as was the case in 1912.

It is not yet possible to estimate, quantitatively, what thermal effect the slope water has on the upper layers of water as it is gradually incorporated into the Gulf of Maine complex. Any increment from this source will tend to cool the surface stratum in the summer but to warm it in winter and early spring.

The chilling effects of the rigorous winter climate of the land mass to the west and of the Nova Scotian current, balanced against solar warming plus the warming effect of the slope water and of the surface indrafts from the Browns Bank–Cape Sable deadwater region, maintain a comparatively constant state in the gulf from year to year; but it is easy to see how any one of them, if more or less effective than usual, might profoundly influence its waters. In attempting to determine the causes of such fluctuations as have been recorded, the evidence of salinity, as well as of temperature, must be weighed.

Unusually high summer temperatures, with normal salinity, might result either from a mild winter preceding, from unusually rapid solar warming during the spring, or from a smaller increment from the Nova Scotian current than normal. High temperature, with very high salinity, would point either to an unusual inflow of slope water during the preceding winter or to one of the rare overflows of tropic water (p. 836). Abnormally low summer temperatures, with normal salinity, would naturally follow any cold winter or spring (cases in point are 1916 and 1923). If coupled with unusually low salinity, an unusual extension of the Nova Scotian current would be indicated, though this same state might result from a cold winter followed by greater river freshets than usual, a combination not unknown. Abnormally low summer temperature, coupled with high salinity, would result if more slope water than usual was then flowing into the gulf and if it was being incorporated with the overlying water more rapidly than usual.

Temperatures and salinities lower than usual along the outer part of the continental slope abreast the gulf in summer would be conclusive evidence of some unusual expansion of water from the northeast, such as seems actually to have occurred in 1916 (p. 848). If combined with very high salinity, very low temperatures along the edge of the continent would be good evidence of some upwelling from the abyss; and although no upwelling of this sort has come under direct observation off the Gulf of Maine region, or seems likely to occur there, events of this sort would have such a wide-reaching effect on local hydrography that strict watch should be kept for them.

SALINITY[71]

GENERAL SUMMARY

The account of the salinity of the gulf may commence, appropriately, with a brief summary, both because the general reader may find in it information sufficient for his wants and to serve as introductory to the more detailed description.

The Gulf of Maine falls among the less saline of inclosed seas; the salt content of its waters averages very much lower, for instance, than that of the Mediterranean, somewhat lower than that of the North Sea, but higher than that of the Baltic. A close parallel to the Gulf of Maine, in salinity, is to be found in the Skagerak, connecting the Baltic with the North Sea. This relationship was to have been expected because the continental waters along the northwestern margin of the Atlantic are decidedly less saline, as a whole, than on the European side.

Compared with the Gulf of St. Lawrence, the Gulf of Maine shows slightly the higher mean salinity at the surface; but the deep waters of these two gulfs agree very closely in this respect, as they do also in temperature.

Perhaps the most notable feature of the gulf, from the present standpoint, is the abrupt contrast between the decidedly low salinity (averaging only about 32 to 32.5 per mille at the surface and 32.8 to 33 per mille at 100 meters' depth) over and within its offshore rim, and the very much salter (>35.5 per mille) water of the so-called "Gulf Stream," always to be found only a few miles to the seaward of the edge of the continent. This contrast finds its counterpart in the temperature and also in the color of the water.

The Gulf of Maine is also interesting for the wide regional variations in salinity in its inner waters, where, in spite of its small extent, the extremes recorded (about 27 to 35 per mille) cover a range wider than that of the entire Atlantic basin outside

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[71] In modern oceanographic parlance the degree of saltness, or "salinity," of the sea water is expressed as the total weight, in grams, of the solids in a state of solution in 1,000 grams of water. This relationship "per thousand," or "per mille," is chosen rather than the more familar term "per cent," merely for convenience to avoid the constant use of small fractional parts.

the 1,000-meter contour. However, even such a range as this is narrow, as compared to temperature, for with the mean salinity of the gulf falling close to 32.5 per mille the extreme variation is not more than 20 per cent. Consequently, I must caution the reader that while emphasis is laid on these variations in the following pages, they are actually so small, from season to season and from place to place, that their measurement requires careful chemical or physical tests. They could not be detected by any human sense. To use a homely example, no one, I fancy, could distinguish the saltest water of the gulf from the freshest by its taste, but no one could fail to tell the temperature of winter from that of summer if he dipped his hand in the water or by feeling the spray on his face.

The gulf is invariably saltest in the eastern side of its trough and in the Eastern Channel, which connects the latter with the open ocean. It is freshest in the coastwise belt along its northern and western shores and along the western shoreline of Nova Scotia, as appears repeatedly on the charts of salinity for various levels and seasons.

The fact that the water over Georges Bank (the shoal southern rim of the gulf) is not salter than the basin to the north of it deserves emphasis because its proximity to the oceanic waters of the "Gulf Stream" might lead us to expect high salinities there.

A wide seasonal variation in the salinity of the surface is characteristic of coastwise waters in boreal latitudes, the water freshening at the season of the spring freshets and then gradually salting again as this inrush of river water is incorporated by the mixings and churnings caused by the tides, winds, and waves.

The Gulf of Maine is no exception to this rule. The widest seasonal variations so far actually recorded there at any given station are from about 28 per mille in April to about 32.7 per mille in winter in the Bay of Fundy (fig. 165), and from about 28.3 per mille in May to about 32.3 per mille in early March in the opposite side of the gulf, a few miles off the mouth of the Merrimac River (p. 813). Such changes, however, are confined to the superficial stratum of water not over 40 meters thick. The bottom waters of the gulf deeper than 100 meters see very little alteration in salinity from season to season. The salinity has also proved unexpectedly constant from year to year in all parts of the gulf at any given season.

The Gulf of Maine is characterized by a considerable vertical range in salinity over all but its most tide-stirred portions, contrasting strongly in this respect with the North Sea, across the Atlantic, where the salinity as a whole is more nearly uniform from the surface downward. The vertical range is widest in spring and summer, when the surface as a whole is freshest, narrowest toward the end of the winter; greatest, too, where the stirring effects of the tides are least, as in the western side of the gulf off Massachussetts Bay, and least where tidal currents keep the water more thoroughly churned, as in the Bay of Fundy in one side of the gulf or on Nantucket Shoals in the other.

In summer, and in the coastwise zone, the increase in salinity with depth averages most rapid from the surface down to a depth of about 50 to 75 meters; but there are many exceptions, and in the deep basin of the gulf the salinity gradient may be nearly uniform, surface to bottom, or the rise in salinity may be found most rapid as the bottom is approached.

DETAILED ACCOUNT OF SALINITY

The detailed account of the salinity of the gulf may well commence with its state at the end of the winter and during the first days of spring, both because this is the season when variations in salinity, both regional and vertical, are least, and because this choice of a point of beginning will parallel the description of the temperature of the gulf (p. 522).

FEBRUARY AND MARCH

At the end of February and during the first week of March the salinity of most parts of the gulf is at or near its maximum for the year, except close to the mouths of the larger rivers. It is also most nearly uniform then regionally, having had a range of only 1.3 per mille from station to station at the surface in March, 1920. In the offshore parts of the gulf the salinity is then also close to uniform vertically, from the surface down to a depth of 40 to 50 meters, but increases at greater depths down to the bottom of the trough, as is the general rule in all parts of the Gulf of Maine at all seasons.

SURFACE

During the last week of February and the month of March of 1920 (which we must, perforce, take as representative, being the only year when we have made a general survey of the gulf at this season) the surface water was freshest (31.3 to 32 per mille) along a narrow band fringing the coast between Portland and the eastern boundary of Maine (fig. 91); and it is probable that equally low salinities prevailed in the more inclosed bays and in the mouths of harbors all around the coast line of the gulf at that time. The curves for successive values show that this band of water, less saline than 32 per mille, was probably not wider than 20 miles (measured from the outermost islands or headlands) on any line normal to the coast, with rather an abrupt transition to salinities higher than 32 per mille a few miles to the seaward of the 100-meter contour. In outlining the distribution of salinity farther out from the land, the curve for 32.5 per mille is the most instructive, its undulating course marking an artificial boundary between the fresher and salter waters. Water fresher than this overspreads the entire northwestern and western portions of the gulf at this season and its eastern side as well, spreading offshore to include the whole western half of Georges Bank, a considerable area off Penobscot Bay, and the whole breadth of the continental shelf (including Browns Bank) to the southward of Cape Sable.[79]

The salinity of the surface water in the offing of the cape is especially interesting at this season as evidence of the extent to which the icy waters of the Nova Scotian current (characterized equally by low salinity) have begun to flood westward past the cape into the Gulf of Maine. In 1920 the situation of the isohaline for 32.2 per mille on this March chart clearly shows that the freshest (also the coldest) core of this drift lay well out from the shore off southern Nova Scotia, directed toward Browns Bank, and that it had not yet passed the longitude of Cape Sable in appreciable volume. The low salinity of the waters that then skirted the western

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[79] The surface salinity was only 32.16 per mille at our outermost station on the Shelburne profile (20077) on March 19.

shores of Nova Scotia (<32.2 per mille) is thus shown to be of local origin—i. e., merely a part of the generally low salinity of the coastwise belt, resulting from the drainage of fresh water from the sundry streams that empty along that sector of the coast line.

At the time of our spring cruise in 1920 the surface water over the eastern half of Georges Bank and in the southeastern part of the basin of the gulf was more saline than 32.5 per mille, this area of high salinity indenting Y-like into the inner parts of the gulf, with its one arm extending northward along the eastern side of the basin to the mouth of the Bay of Fundy and the other westward toward Cape Cod in a manner better shown on the chart (fig. 91) than verbally. It is probable that this contrast in salinity between the western and eastern ends of Georges Bank is characteristic of this season of the year.

The distribution of salinity on Georges and Browns Banks also makes it probable that the saltest surface water in the Eastern Channel and in the neighboring part of the basin of the gulf then took the form of an isolated pool entirely cut off from the still more saline surface water (>33 per mille) of the Atlantic basin outside the edge of the continent, reflecting some local stirring or upwelling of the water.

Apparently it would not have been necessary to run out more than about 25 to 30 miles from the continental edge of Georges Bank in February and March to have encountered surface salinities of 33 per mille and upward; but the low value (32.16 per mille) at our outermost station on the Shelburne profile (station 20077) suggests that the isohaline for 33 per mille then departed farther and farther from the continental slope, passing eastward from Georges Bank, to leave a widening wedge of less saline water next the edge of the continent.

The most spectacular event in the yearly cycle of salinity of the Gulf of Maine is the sudden freshening of the surface near its shores, which follows the spring freshets of its rivers, an event happening earlier or later, according to the date when the snow that blankets New England, New Brunswick, and Nova Scotia melts and the ice in the lakes and streams goes out. In this respect the spring of 1920 was late, following a severe winter. The effect of this outpouring of land water makes itself evident, by lowered salinity at the surface, earlier off some parts of the coast than off others. However, this regional variation does not correspond directly to the latitude of the rivers concerned, because the effect of the Kennebec was made evident in 1920 by surface salinity nearly 1 per mille lower close in to its mouth (station 20058) than either to the westward or to the eastward of it as early as March 4 (fig. 91); but any effect that the discharge from the Merrimac may have had on the preexisting salinity up to that date must have been confined to the immediate vicinity of its mouth, because the surface was then about the same for the general sector between Cape Elizabeth and Cape Ann as for the offing of the river (32.2 to 32.3 per mille).

In 1925 (an earlier spring on land as well as in the sea) fresh water from the Merrimac had developed a streak of low surface salinity (30.7 per mille) for about 6 miles out from the mouth of the river by March 12, with slightly higher surface values (31 to 32 per mille) to the north and south (*Fish Hawk* stations 20 and 28, cruise 9, pp. 1009, 1010). While higher values in Massachusetts Bay (32.4 to 32.9 per mille; *Fish Hawk* cruise 8, March 10, stations 2 to 18A; p. 1004) prove that low salinities from this source had not yet spread southward past Cape Ann, the freshets from the several rivers produce a cumulative freshening in the coastwise belt from mid-March on, which finally involves the entire periphery of the gulf to greater or less extent (p. 723).

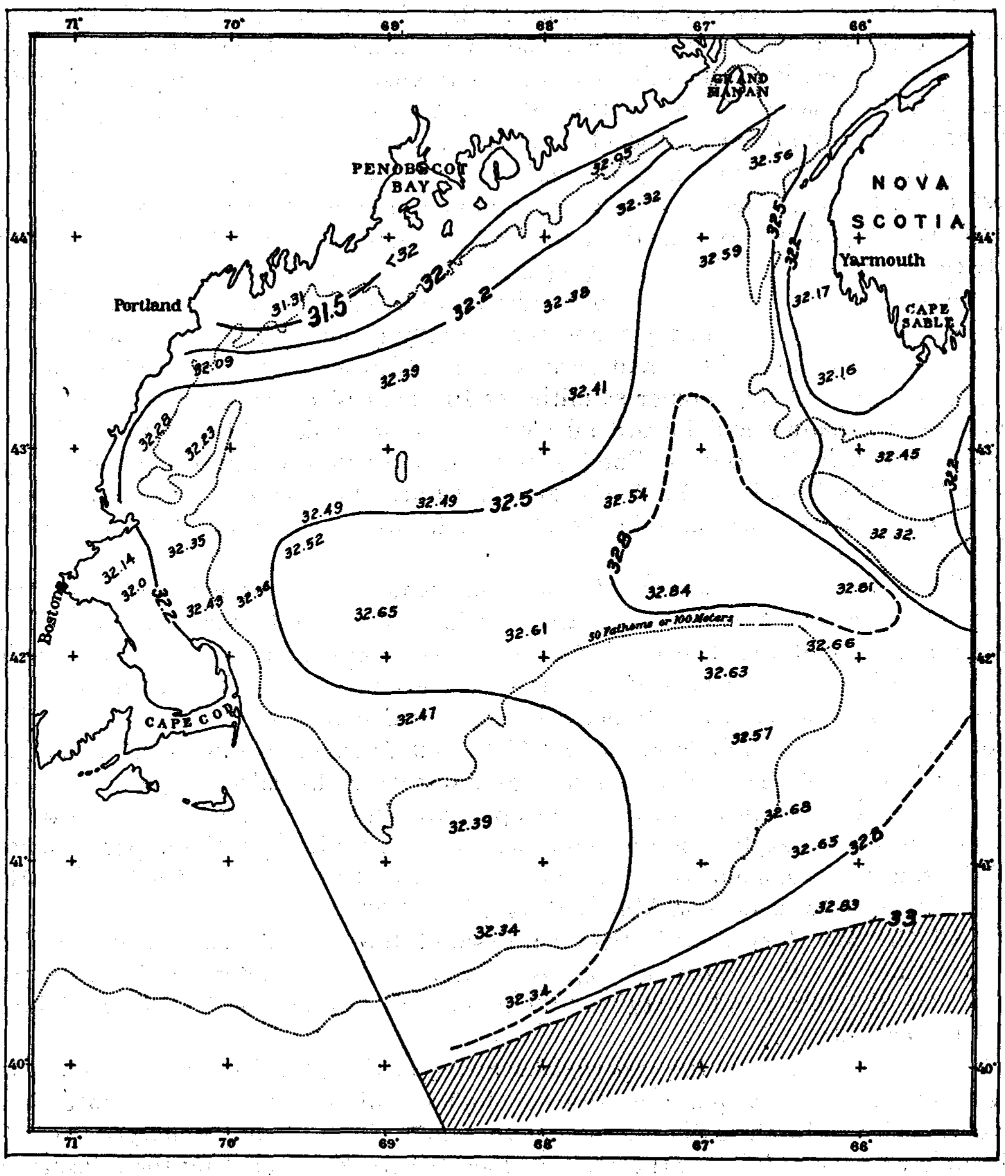

Fig. 91.—Salinity at the surface, February 22 to March 24, 1920. The isohaline for 33 per mille is assumed

VERTICAL DISTRIBUTION

Our data on salinity for the years 1913, 1920, and 1925 show that a very close approach to vertical uniformity obtains over the gulf down to a depth of 40 to 50 meters and outside the 100-meter contour during the last week of February and the first part of March. Thus, in 1920 the widest range between the surface and the

40-meter level for this whole area was only 0.1 per mille, including the deep water off the southeastern slope of Georges Bank (station 20069) and the continental shelf abreast southern Nova Scotia (stations 20073 to 20077).

Our several stations in Massachusetts Bay, for various dates in March during the three years of record, have shown the upper 40 meters of water equally homogeneous there; and it is probable that this generalization would apply to the entire coastal zone of the gulf outside the outer islands during the last half of February, except close to the mouths of the larger rivers.

In March, 1920, homogeneity characterized the whole column of water in the western part of the basin of the gulf, as limited by a line running southeastward from Penobscot Bay, down to a depth of 100 to 150 meters, with the difference in salinity between 40 and 100 meters averaging almost exactly the same as between the surface and 40 meters (about 0.05° per mille). In other words, stirring by tides and waves is active enough to keep the water virtually equalized in salinity down to this depth during the late winter and early spring. However, our March stations have all yielded considerably higher salinities at 100 meters' depth than at 40 meters in the Eastern Channel and inward all along the eastern side of the basin of the gulf (not however, in the Bay of Fundy), with an average difference of about 0.6 per mille (stations 20055, 20056, 20071, 20072, 20081, 20082, and 20086) and a maximum range of 1.43 per mille in the channel between Georges and Browns Banks (station 20071).

The presence of this tongue of more saline water at 100 meters combines with a more or less constant tendency toward upwelling from the deeper strata to raise the lower boundary of the stratum, equalized by vertical stirrings, some meters higher there than in any other part of the gulf. An even wider vertical range of salinity between the 40-meter and 100-meter levels, recorded over the shelf south of Nova Scotia that same March (stations 20074 to 20077; range of 0.8 to 2.7 per mille), suggests a drift of the fresher coastal water out over the salter slope water;[80] and this, or a reciprocal movement of the slope water in toward the slope on bottom, is also the probable explanation for almost as steep a gradient in the upper 40 meters off the southwest slope of Georges Bank on February 22 (station 20044 and 20045), and off its southeast face on March 12 (station 20069; fig. 92).

All the March stations in the open basin of the gulf also show a considerable vertical increase in salinity at depths greater than 100 meters, with a maximum difference of 1.26 per mille between 100 meters and 150 (station 20053), a minimum of 0.14 per mille.

The homogeneity of the superficial stratum of the gulf, characteristic of the last weeks of winter, gives place to the devolopment of a more stratified state in the coastal belt in March as the increasing volume of fresh water discharged from the rivers lowers the salinity of the surface along the tracks affected by their discharges. In the year 1920 the discharge from the Kennebec, perhaps combined with water from the Penobscot, had reduced the salinity of the surface water off Boothbay fully 1 per mille below that of the 40-meter level by March 4 (station 20058).[81] In 1925 the

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[80] The surface stratum of low salinity cut by the Shelburne profile for March is the southernmost extension of the Nova Scotian current (p. 832).

[81] No observations were taken at the mouth of Penobscot Bay during this month, consequently I can not state how far seaward the outflow from the Penobscot River may then have influenced the vertical distribution of salinity.

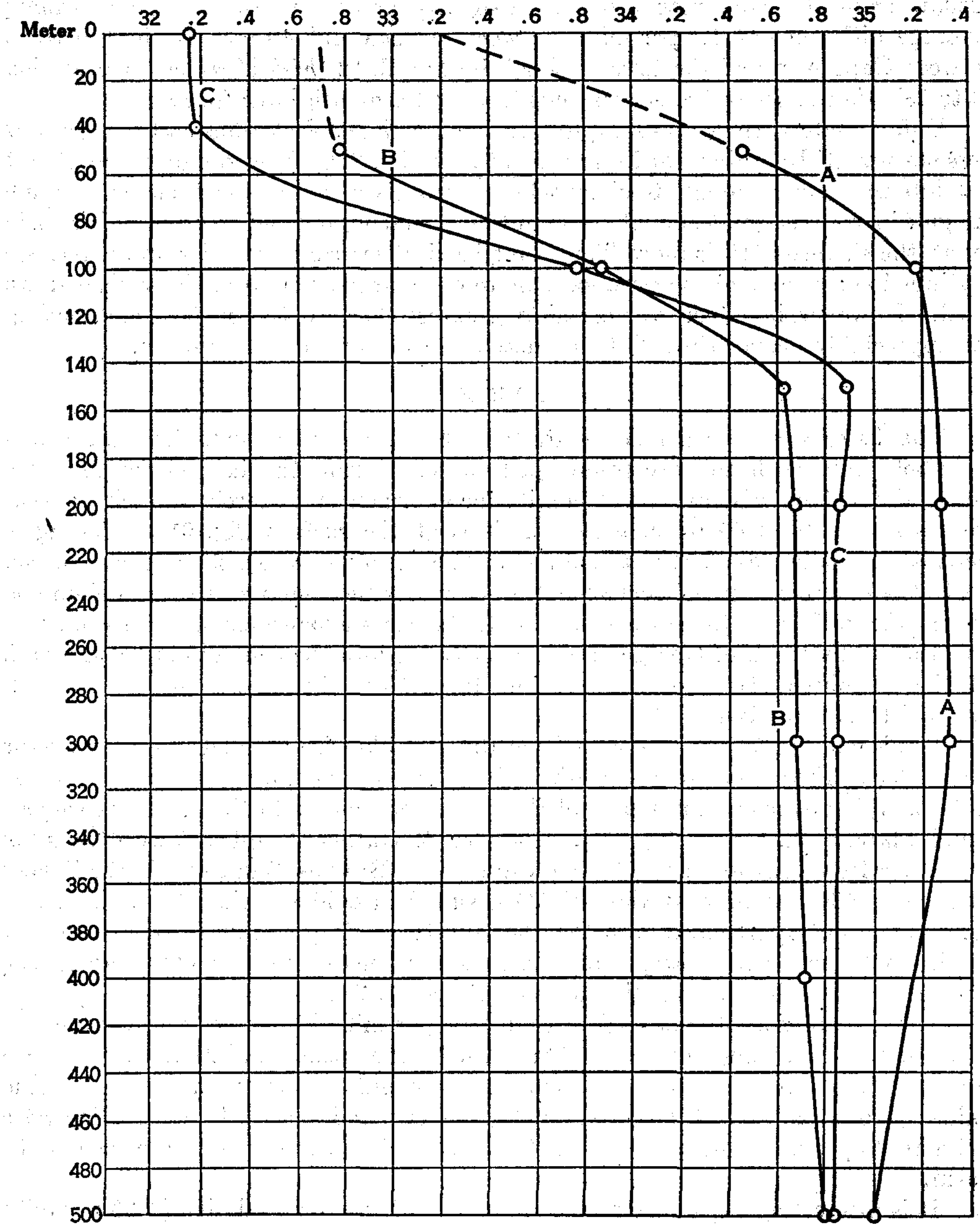

FIG. 92.—Vertical distribution of salinity on the continental slope abreast the gulf and off Shelburne, Nova Scotia, February to March, 1920, A, southwest of Georges Bank, March 22 (station 20044); B, off the southeast slope of Georges Bank, March (station 20069); and C, off Shelburne, Nova Scotia, March (station 20077). The dotted curves are assumed

outflow from the Merrimac produced a slightly greater vertical range of salinity (average difference of 1.5 per mille between surface and 40 meters) in the region between Cape Ann and the Isles of Shoals by March 12 (*Fish Hawk* cruise 9, stations 20 to 28), though its full effect was not felt until a month later (p. 725).

Unfortunately, the water samples for these *Fish Hawk* stations and for the *Albatross* station off Boothbay for March 4, 1920 (station 20058), were not taken at vertical intervals close enough to show whether the river water was then pouring into the gulf in volume great enough to maintain a sharply defined stratum of low salinity at the surface. It is more likely that vertical stirring by tides and waves still continued active enough to produce a more even gradation from the surface downward. However, its effect was certainly greatest close to the surface and perhaps not appreciably deeper than 20 to 40 meters until later on in the season.

40 METERS

Thanks to the homogeneous state that characterizes the superficial stratum of the whole gulf (with the exceptions just noted) during the late winter and early spring, the regional distribution of salinity for February and March is much the same down to a depth of 40 to 50 meters as it is at the surface (fig. 91). The agreement is especially close for the isohaline for 32.5 per mille, which shows the same contrast at 40 meters (fig. 93) between fresher water near land and salter offshore all around the gulf as at the surface, and with the same expansions of low salinity out over the western half of Georges Bank, southward into the central part of the basin off the Penobscot Bay region, and out from Nova Scotia across the Northern Channel to Browns Bank.

The isohalines for the 40-meter level (fig. 93) likewise parallel those for the surface in locating the axis of the freshest band on the Shelburne profile (< 32 per mille) as lying over the outer part of the shelf, not close in to that coast as we have found it later in the season (fig. 132). However the rather abrupt east-west transition in salinity from this tongue to higher values over Browns Bank and in the Eastern Channel (32.86 per mille, station 20071) is sufficient evidence that the Nova Scotian current had not appreciably affected the salinity so deep as this farther west than longitude 65° up to this date, though some slight movement of water may already have taken place in this direction at the surface (p. 703).

The distribution of water salter than 32.5 per mille is also very nearly the same at 40 meters as at the surface in March, with the same gradation lengthwise of Georges Bank from lower values (about 32.4 per mille) at the western end to higher values (about 32.6 to 32.7 per mille) at the eastern, and to slightly more saline water (32.8 to 33 per mille) in the Eastern Channel and in the southeastern part of the basin.

It is interesting to find a circumscribed pool of very high salinity (>33 per mille) in the eastern side of the basin at this level, which could have resulted only from some local upwelling.

In winter and early spring, when the water has little vertical stability to resist vertical currents, events of this sort are to be expected locally over small areas as the result of tidal churnings, or caused by the wind. The distribution of salinity at different seasons shows that the basin is most subject to them in its eastern side, and offshore gales often bring up water from below in volume great enough appreciably to affect the temperature and salinity of the surface along the western shores of the gulf during the later spring (p. 729).

It is not clear whether the water salter than 32.8 per mille, which occupied the southeastern part of the gulf in March, 1920, was then continuous with still higher salinities offshore at the 40-meter level, as is suggested on the chart (fig. 93), or whether it was inclosed by slightly lower salinities at the mouth of the Eastern Channel, as seems to have been the case at the surface at the time. A station in the offing of the channel would have settled this question.

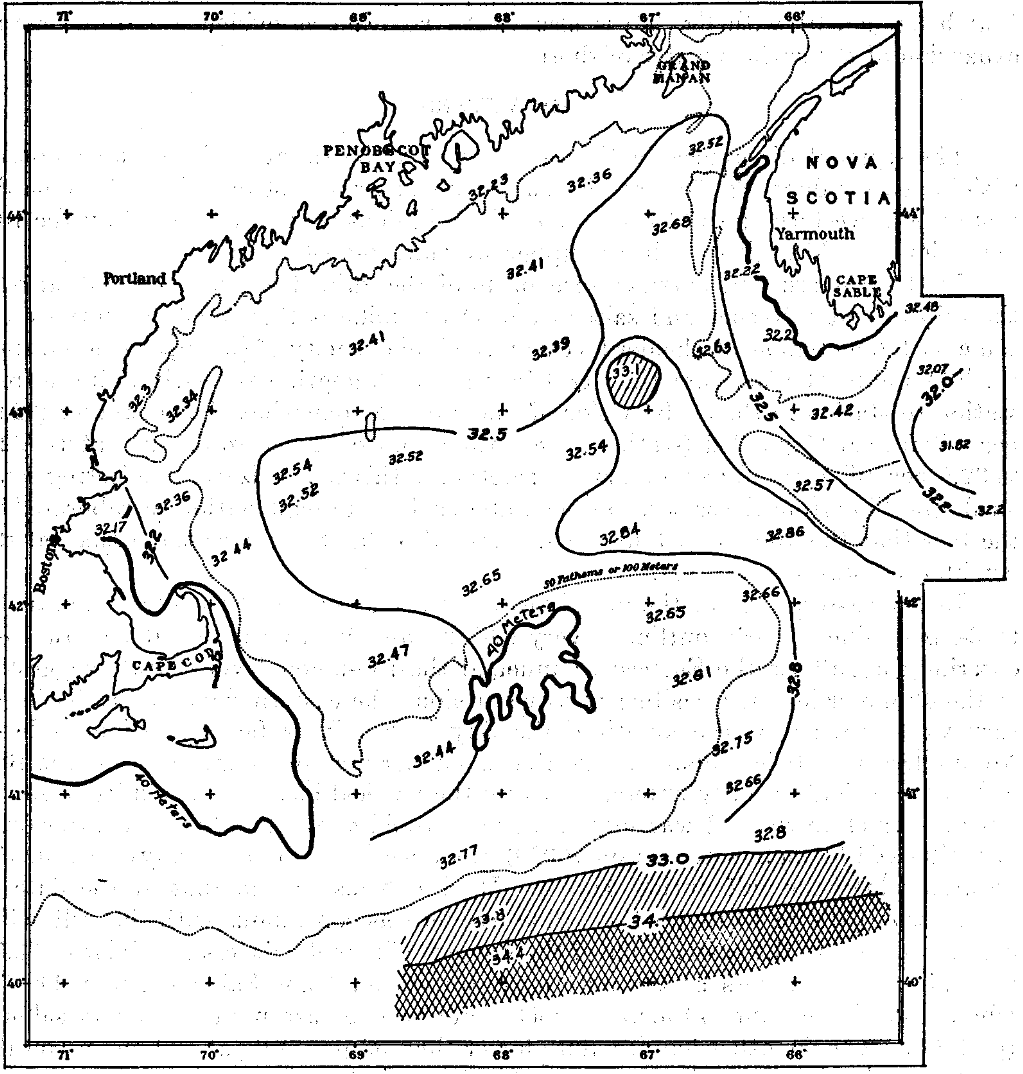

FIG. 93.—Salinity at a depth of 40 meters, February 22 to March 24, 1920

The only important difference between the distribution of salinity at the surface of the gulf and at 40 meters for March is in the coast sector between Portland, Me., and Penobscot Bay, where the freshening of the surface by river water (p. 704) does not at first affect the salinity to as great a depth.

The fact that moderately high salinities (34 per mille) lay closer in to the seaward slope of Georges Bank at 40 meters depth than at the surface in February and March (cf. fig. 91 with fig. 93) is also worth mention as evidence of some recent expansion of the surface water offshore.

100 METERS

The regional differences in the rate at which the salinity of the gulf increases with increasing depth (p. 706) result in a much wider contrast in salinity between the eastern and western sides of the gulf in the mid depths (as represented by the 100-meter level by March) than in the upper stratum (fig. 94).

In the western and northwestern parts of the gulf, it is true, the mutual relationship of water fresher and salter than 32 per mille is then made essentially the same at 100 meters as at shoaler levels by the homogeneity of the superficial stratum (p. 705) and by the fact that the slight increase with depth was nearly uniform from station to station in that subdivision of the gulf. A somewhat higher salinity (32.92 per mille) near Cape Cod (station 20088) than that of the surrounding waters (32.5 to 32.6 per mille) is only an apparent exception to this generalization, reflecting some local upwelling from the salter, warmer waters below, an explanation corroborated by the fact that the 100-meter temperature was also slightly higher there than at the neighboring stations (fig. 13).

In the eastern side of the gulf, however, the curves for the several values (33 to 34 per mille) clearly outline a very definite and highly saline but narrow core entering the gulf via the Eastern Channel, at the 100-meter level (hardly suggested at the 40-meter level), spreading northward along the eastern slope of the basin, to turn westward across the mouth of the Bay of Fundy as far as the longitude of Mount Desert. It is probable, also, that a smaller increment was entering the Bay of Fundy, or had recently entered, because the vertical increase in salinity from the 40-meter level downward was somewhat more rapid at the mouth of the latter (32.7 per mille at 100 meters at station 20079) than we have found it anywhere in the western side of the gulf during March. It also seems certain that at the date of observation (March 13 to 23) this saline tongue was continuous with the still salter oceanic water via the eastern side of the Eastern Channel, witness a salinity of 33.78 per mille at 100 meters at the outermost station off Cape Sable (station 20077), where the surface and 40-meter levels were by contrast notably low in salinity (p. 1000). On the other hand, values lower than 33 per mille at 100 meters on the eastern peak of Georges Bank (station 20070) and along its southeast face (station 20068) suggest that water less saline than 33 per mille was then drifting out of the gulf along the western slope of the channel, to pool off the southeast face of Georges Bank and so to hold the oceanic water (>35 per mille) at least 60 miles out from the latter. However, this pool of water of low salinity (and of low temperature) extended only a few miles around the tip of the bank to the westward, with salinities higher than 34 per mille washing its southern face. If 35-per mille water did not actually touch the slope of the bank to the westward of longitude 68° on February 22 (stations 20044 and 20045), as it apparently had off New Jersey on February 21 (station 20043), it was not separated from the edge of the continent there by more than 10 miles of lower salinities at the 100-meter level at that time.

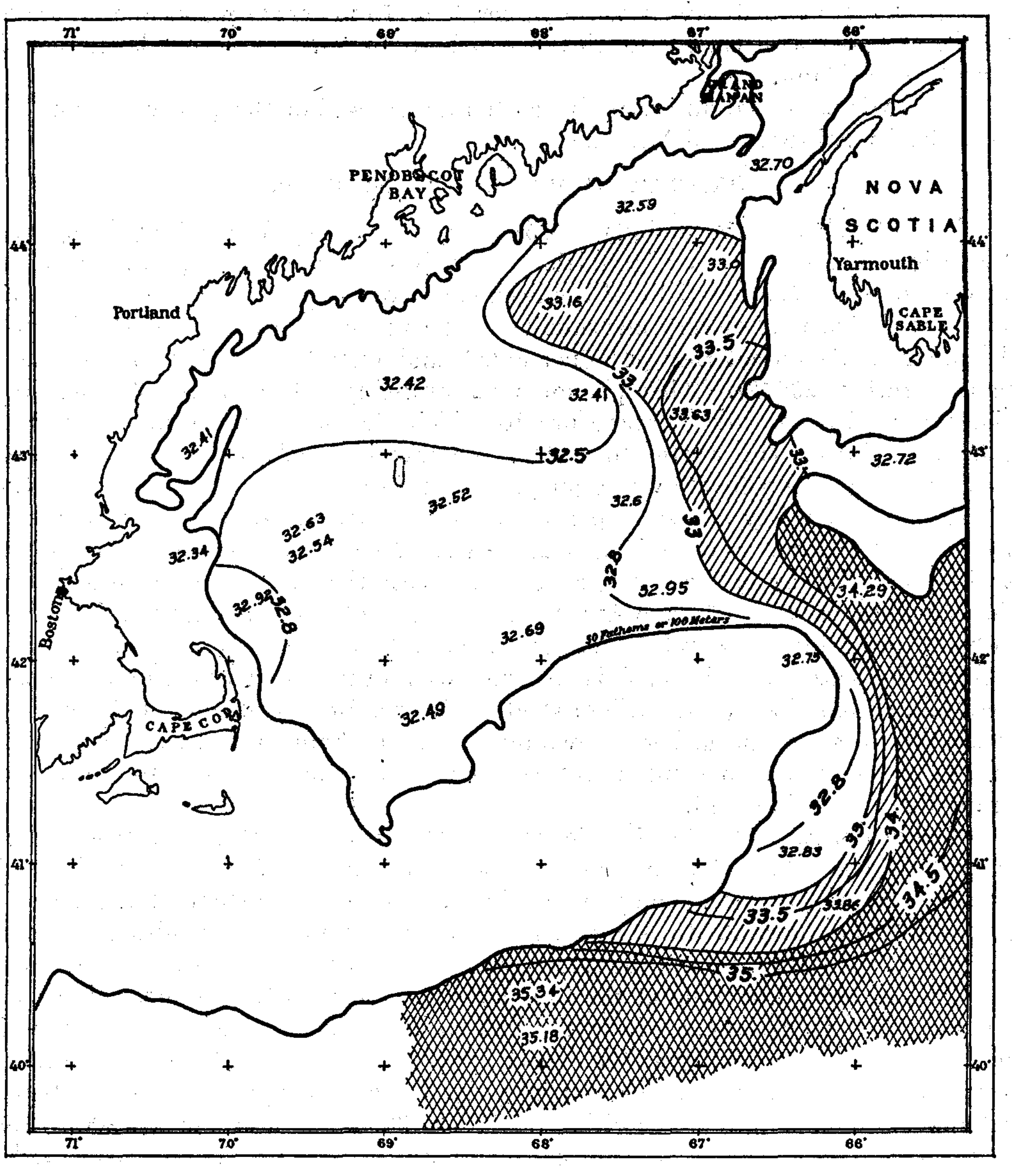

Fig. 94.—Salinity at a depth of 100 meters, February 22 to March 24, 1920

The agreement between the March charts for temperature (p. 526, fig. 13) and for salinity at 100 meters (fig. 94) is remarkably close in the eastern side of the gulf, the two combined affording evidence as good as could be asked that warm saline water was then actually flowing into the gulf along the eastern side of the Eastern

Channel, or had been so flowing shortly previous. The failure of the Nova Scotian current of low salinity to show at all in the 100-meter salinities for March, 1920, either on the deeper parts off the shelf abreast of Shelburne, Nova Scotia, or in the southeastern part of the Gulf of Maine, also deserves emphasis as evidence that this current is confined strictly to the upper 50 or 75 meters of water at that season, neither creeping westward through the Northern Channel at deeper levels nor circling Browns Bank.

The regional variation in salinity at 100 meters within the gulf was about 1.86 per mille for February and March, 1920.

SALINITY AT 150 METERS AND DEEPER

The March chart of salinity at 150 meters (fig. 95) is interesting chiefly as an illustation of the west-east gradation from lower values to higher, which has proved generally characteristic of the deep strata of the gulf, complicated, however, by an extensive pool of very low salinity in the northwestern part of the basin, in the offing of Penobscot Bay (<33 per mille), and extending southward past Cashes Bank (station 20052). This phenomenon probably reflected an offshore drift, associated with the low temperature to which the northern coastal zone of the gulf chills during the winter (p. 651). Whether it develops annually, as its low temperature (station 20052) would suggest, is an interesting question for the future.

A salinity slightly below 33 per mille in the extreme southwestern corner of the basin at 150 meters on February 23 (station 20048, 32.97 per mille), apparently entirely inclosed by salter water, contrasting with the increase that took place in the 150-meter salinity off Cape Ann from 33.4 per mille on that date (station 20049) to 33.53 per mille on March 24 (station 20087), illustrates the extent to which the state of the water at this depth is governed by mutual undulations of the shallow (less saline) and deep (more saline) strata. No doubt movements of this sort are constantly in progress, raising or lowering the upper boundary of the bottom stratum salter than 33.5 per mille; but as yet we have not been able to follow these submarine waves in detail.

The localization of salinities higher than 33.8 per mille along the eastern slope of the basin at 150 meters in March, with a maximum of 34.4 per mille in the Eastern Channel, points to some inflow right down to the bottom of the latter at that date (February 22 to March 24) or shortly previous; but with so gentle a gradation in salinity from the one side of the basin to the other, this indraft evidently was (or had been) less rapid at the 150-meter level than at 100 meters, or in smaller volume. Nor is its course within the gulf so definitely outlined by the curves for successive values of salinity at the deeper level. Very little water of this origin, if any, was then flowing over the rim into the Fundy Deep because the 150-meter salinity was considerably lower within the latter (33.01 per mille, station 20079) than in the neighboring part of the open basin (33.7 to 33.9 per mille). Nor had it recently overflowed the shoal rim into the bowl at the mouth of Massachusetts Bay, where the bottom water (150 meters) was about 1 per mille less saline on March 1[83] than equal depths in the neighboring parts of the basin, and the entire column very close to homogeneous, vertically, from surface to bottom.

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[83] Station 20050, 32.39 per mille at 150 meters

In the same way, a March reading of only 32.91 per mille at 175 meters in the trough west of Jeffreys Ledge (station 20061) mirrors the hindrance of free circulation at the bottom (p. 691) by the barrier rim to the north.

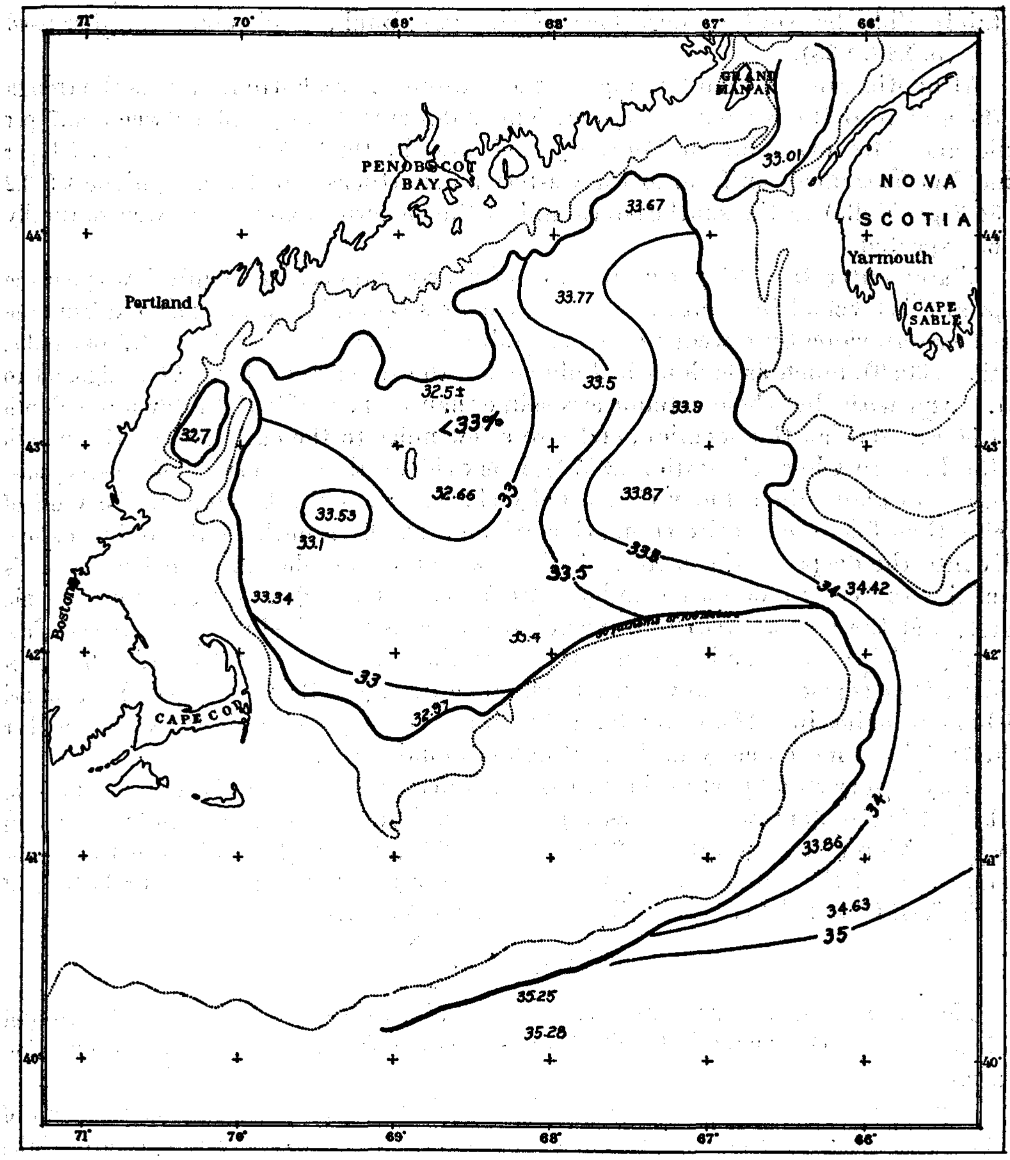

FIG. 95.—Salinity at a depth of 150 meters, February 22 to March 24, 1920

Salinities at depths greater than 150 meters did not demonstrate any inflow as actually taking place into the bottom of the gulf in February and March, 1920. Thus we find a general and comparatively uniform gradation at 175 meters from 33.5 to 33.8 per mille around the inner slope of the basin generally (but only 33.03

per mille in the topographic bight just east of Cashes Ledge) to 34 to 34.2 per mille in the southeast corner (station 20064) and to 34.5 per mille in the eastern side of the Eastern Channel (station 20071). It is probable, however, that a band of slightly fresher water skirted the western slope of the latter down to this depth, as it certainly did the southeastern face of Georges Bank, a phenomenon discussed below (p. 848, 938).

At depths greater than 200 meters the contour of the bottom divides the trough of the gulf into three separate basins: The 200-meter salinity fell between 33.7 per mille and 34.7 per mille in February and March, 1920—lowest (33.8 to 34.1 per mille) and extremely uniform in the western and northeastern channels, highest (33.2 to 34.7 per mille) in the southeastern and in the eastern channels, as was naturally to be expected.

Water salter than 35 per mille (i. e., of nearly full oceanic salinity) washed the slope at this level off the southwest face of Georges Bank, but was separated from the southeastern slope by a wedge of considerably lower salinity (34.6 to 34.7 per mille, station 20069), much as is described above for the shoaler levels (p. 704; figs. 93 to 95). And with the whole column less saline than 35 per mille right down to a depth of 1,000 meters at this location, and also a few miles to the eastward of the mouth of the Eastern Channel (station 20077), it is evident that a very considerable mass of water of about the salinity that usually characterizes the bottom of the Gulf of Maine then filled the entire submarine triangle at the mouth of the only possible inlet into the deeps of the latter. This is a significant phenomenon because it is from this source of moderate salinity (34.5 to 35 per mille), not from pure oceanic water, that the bottom drift into the gulf draws, as is described more *in extenso* below (p. 842). With this moderate salinity extending downward so deep (fig. 92), it is evident that considerable upwelling might take place off the mouth of the channel without bringing into the latter (and thus into the gulf) water of appreciably higher salinity than a more nearly horizontal inflow would bring.

Only a very small part of the gulf is much deeper than 200 meters. The bottom water, at 250 meters, was 34 to 34.2 per mille in both the western and the eastern bowls in March, 1920 (stations 20054 and 20087), with higher values in the southeastern part of the gulf,[84] corresponding very closely to the salinity of the bottom of the Eastern Channel (34.7 per mille) and outside the latter.

PROFILES

The charts for the several levels give a picture of the salinity in horizontal projection, but the spacial distribution is made more graphic by representation in profiles.

The essential contrast between the low salinity that characterizes the Gulf of Maine at all seasons and the much more saline oceanic water to the seaward of the continental edge is illustrated for February and March by two profiles running from north to south across the gulf and its southern rim, the one from the offing of Cape Elizabeth (fig. 96), the other from the offing of Mount Desert Island. (Fig. 97.) Taken in conjunction with the corresponding profiles for temperature

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[84] Station 20064, salinity approximately 34.8 per mille from 250 meters right down to the bottom in 330 meters.

(figs. 15 and 16), they show the water freshest where coldest (i. e., inshore), saltest where warmest—a relationship that prevails all along the North American seaboard between the latitudes of Chesapeake Bay and of Cape Breton, at the time of year when the temperature is at its lowest. The profiles for salinity differ, however, from those for temperature, in cutting across alternate bands of fresher water next the coast, salter in the basin, fresher again over Georges Bank, and saltest of all at their seaward ends outside the edge of the continent. This succession on the western profile (fig. 96) mirrors the expansion of water of low salinity (32.5 per mille) out from Cape Cod across the western part of Georges Bank. On the eastern profile, however (fig. 97), the contrast between slightly lower values over Georges Bank (32.6 to 32.7 per mille) than over the basin immediately to the north of it (32.8 per mille) is associated with the indraft via the Eastern Channel, which interrupts the picture by raising the salinity of the upper stratum of that side of the basin slightly above the values that might otherwise be expected there. In brief, then, the contrast between basin and bank is caused on the one profile by outflow over the latter from inshore, but on the other profile by an inflow around the bank into the gulf.

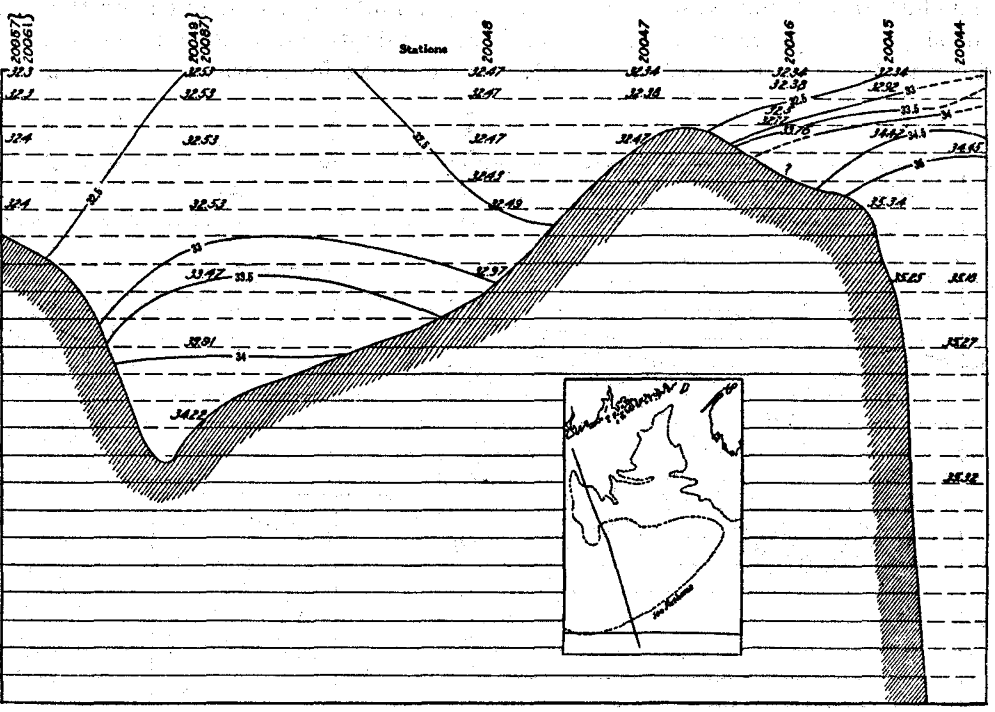

FIG. 96.—Salinity profile running southward from the offing of Casco Bay, across Georges Bank, to the continental slope, February 22 to March 5, 1920

The two profiles agree in showing comparatively low and uniform salinities (temperatures, as well) at the offshore ends in the upper stratum, with the curves for the successive values so nearly horizontal there that it would evidently have been necessary to run some distance farther offshore to have reached the inner-edge of the so-called "Gulf Stream" on either of these lines.

The deeper strata of the western profile (fig. 96), however, illustrate the proximity of oceanic water to this end of the bank; evident, too, on the charts (figs. 94 and 95) by a very rapid rise in salinity, with increasing depth at the outer stations (20044 and 20045) to oceanic values of 35 per mille and higher within 60 to 70 meters of the surface and down the slope from the 100-meter level. On the eastern profile, however (fig. 97), the vertical change in salinity was not only less abrupt at the offshore end, but water as saline as 35 per mille lay so far out from this part of the slope that the profile did not reach it at any depth, although readings were taken down to 1,000 meters (station 20069). Nor have we found water as saline as 35 per mille touching the southeastern face of the bank later in the spring (fig. 117) or in the summer. The presence of a wedge of water considerably less saline (and colder) than the so-called "Gulf Stream," sandwiched in between the latter and the slope in this general location, is thus revealed as clearly in cross profile as it is in horizontal projection.

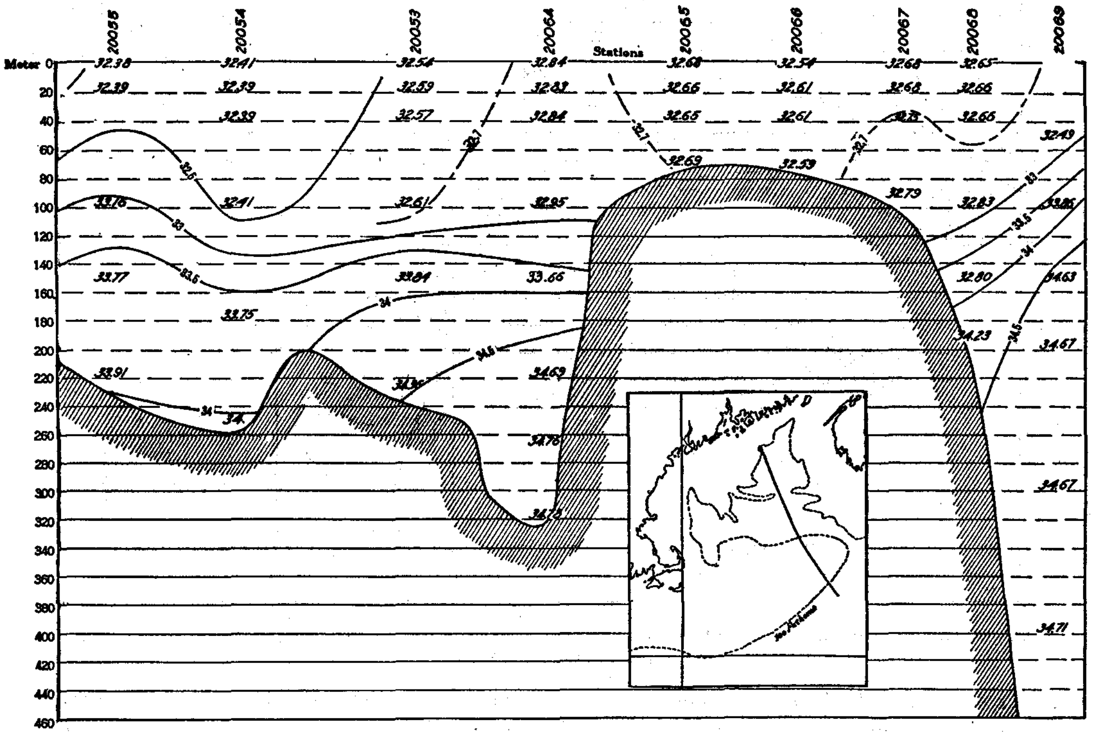

FIG. 97.—Salinity profile running from the vicinity of Mount Desert Island, southward across the gulf and across Georges Bank to the continental slope, March 3 to 12, 1920

Apart from these general features, the most instructive aspect of the western member of this pair of profiles is its graphic presentation of a very notable difference in the vertical distribution of salinity between the basin of the gulf to the northward of the crest of Georges Bank (where the water was very close to homogeneous from the surface downward to a depth of 100 meters) and the southern half of the bank, where salinity increased so rapidly with depth that a greater range was compressed into the upper 40 meters than characterized the whole column of water (280 meters) in the basin.

Both the profiles (figs. 96 and 97) also show a contrast of the reverse order in the deeps between the oceanic slope to the south (nearly homogeneous in salinity below the zone of most rapid vertical transition at 50 to 140 meters) and the gulf basin to the north, where salinity increased from the 100-meter level down to the bottom. Undulations in the thickness of the salt bottom waters or submarine waves also appear on both profiles, evidence of rather an active state of vertical circulation at the time, with the isohalines for 32.5 per mille and 33 per mille suggesting a tendency toward upwelling in the northeastern part of the basin.

The rather marked contrast in the salinity of the bottom water of the eastern profile (fig. 97), between 34 per mille to the northward of the ridge that divides this side of the basin into a northern and southern bowl, and upwards of 34.5 per mille at an equal depth to the south of it, illustrates the very important rôle that such an irregularity of the bottom may play in directing the circulation of the water. In the present instance the bottom is to some extent divided by the ridge, as the charts for the 100 and 150 meter levels (figs. 94 and 95) also show, water from its left-hand side being responsible for the high bottom salinities in the southern side of the basin on this profile (stations 20053 and 20064), whereas its eastern branch drifts northward chiefly to the eastward of station 20054.

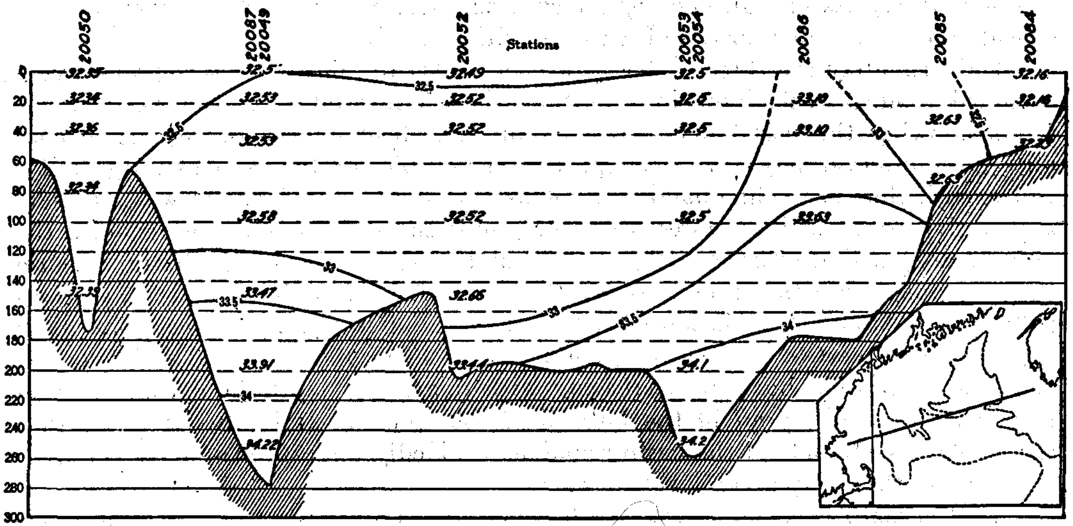

FIG. 98.—Salinity profile running eastward from Massachusetts Bay, across the gulf toward Cape Sable, March 1 to 23, 1920

This control which the conformation of the bottom exercises over the salinities of the deeper strata of the gulf is made still more evident on a west-east profile (fig. 98) by the contrast between the bottom water of the open basin, on the one hand, and of the deep bowl off Gloucester, on the other, just commented on (p. 712), where the barrier rim of the bowl (station 20050) is so effective an inclosure at this season that its deeper strata show almost no effect of overflows from the deeps of the neighboring basin. A profile running out from the Isles of Shoals would show a contrast of this same sort, and due to the same cause, between the trough to the west of Jeffreys Ledge (station 20061) and the basin to the east of it, though with the actual difference in salinity not so great between the two sides of this rather steep ridge because this particular trough is open to the north.

The two phases of the salinity of the gulf that claim most attention in the first days of spring, before the Nova Scotian current has spread westward past Cape Sable, are the vernal freshening from the land, already mentioned (p.704), and the state of the water in the eastern side, where the inflowing bottom current is chiefly concentrated. The latter is illustrated graphically in east–west profile (fig. 98) by a very evident banking up of the saltest bottom water (salter than 33.5 per mille) to within about 80 meters of the surface on the eastern slope of the gulf (station 20086), when it lay nearly 100 meters deeper in the western side of the profile (station 20087, March 23), and by the contrast between its high salinity and the considerably less saline masses of water on either hand.

Unfortunately the three eastern stations (20084 to 20086) on this profile were occupied about 3 weeks later, in date, than those immediately to the westward of them, allowing the possibility that a cumulative development of the saline core during the interval may have been partly responsible for the contrasting salinity. But even if the most saline band was not as definitely limited on its western side, at any given date, as it is represented, the profile certainly does not exaggerate the gradation in salinity between the eastern and western sides of the basin, because water samples were taken in both at the same date (March 23 and 24, stations 20086 and 20087). A variation of at least 1 per mille in salinity is therefore to be expected from west to east across the gulf at the 40 to 100 meter level during the last week of March, but one decreasing with increasing depth from that stratum downward to virtually *nil* in the bottom of the trough. It is also probable that the whole western side of the basin remained decidedly uniform in salinity throughout the month at any given level (p. 722).

Had vernal freshening affected either end of this profile up to the date of observation (to March 24), the surface would have been much less saline than the deeper water at the inshore stations off Massachusetts, on the one side, or off Nova Scotia on the other, just as was actually the case off the Kennebec River on March 4 (p. 706, fig. 91). Instead of a distribution of this sort, however, the water at these stations was nearly homogeneous in salinity from surface to bottom, evidence that values somewhat lower there than in the basin merely represented the gradation of this sort that always exists between the coastal and the offshore waters of the gulf. Consequently the precise values recorded on Figure 98 represent the prevailing state just prior to the date when surface salinity begins to decrease.

This profile also corroborates the horizontal projections of salinity (fig. 91 and 93) to the effect that in 1920 the cold Nova Scotian current did not begin to flood westward past Cape Sable into the gulf before the end of March in volume sufficient to affect the salinity of the latter appreciably, because the band less saline than 32.5 per mille (correspondingly low in temperature) was then narrower in the eastern side of the gulf than in the western, or elsewhere around its periphery for that matter.

The salinity of the water in the Eastern Channel and its relationship to the water over Georges and Browns Banks, which bound it to the west and east, is always of interest, because this is the only possible route by which a deep bottom current can enter the gulf. During the second week of March, 1920, the saltest water in the channel took the form of a definite ridge, with the isohaline for 33 per mille, as represented in cross section (fig. 99), paralleling the isotherm for 3° on the corresponding profile of temperature (fig. 19). The rather abrupt transition from 34 per mille to 33 per mille, made evident at the 50 to 80 meter level by closely crowded isohalines, contrasting with the vertical homogeneity of the shoaler water, marks this as the upper boundary of the saline bottom drift.

The relationship between the vertical distribution of salinity in the trough (station 20071) and on the neighboring shallows of Georges Bank (station 20070; the former much more saline than the latter at depths greater than 40 meters) is evidence of a banking up of the saltest water against the eastern side of the channel and of an overflow across Browns Bank consistent with the effect of the rotation of the earth on any movement of water inward through the channel toward the gulf. On the Georges Bank side, however, this indraft was separated from the slope by a wedge of water lower in salinity as well as in temperature (p. 541); therefore suggesting a counter drift in the opposite direction — i. e., out of the gulf (p. 938)— by its physical character. Unfortunately its lower boundary can not be definitely established from the station data, but the courses of the isohalines in the upper strata on the profile (fig. 99), combined with the contour of the bottom, suggest that it bathed the western slope of the channel down to a depth of at least 170 meters.

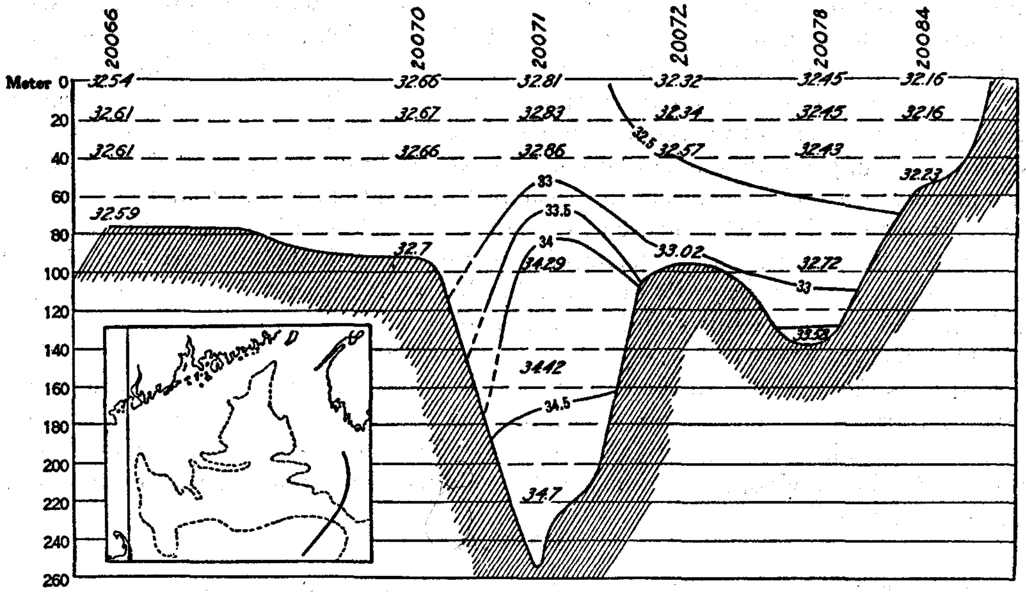

FIG. 99.—Salinity profile running from the eastern part of Georges Bank across the Eastern Channel, Browns Bank, and the Northern Channel, to the offing of Cape Sable, March 11 to 23, 1920

This profile (fig. 99) also corroborates the evidence of the charts (p. 703) that water from the eastward had not yet freshened the upper 50 meters of water as far west as Browns Bank to a value (32.5 per mille) appreciably lower than had probably prevailed there a week or two earlier in the month. This locates the first extension of this comparatively fresh current as directed toward the southeast and not around Cape Sable into the inner part of the gulf, though there is evidence that some of this Nova Scotian water drifts right across the Eastern Channel later in the season and far westward along the outer side of Georges Bank (p. 848).

LIMITS OF WATER MORE SALINE THAN 34 PER MILLE

Salinities higher than 34 per mille, whenever encountered in the deep trough of the gulf, are unmistakable evidence that indraft is either taking place from the region off the mouth of the Eastern Channel at the time, or has taken place so recently that the saline water from this source has not yet been appreciably diluted during the sojourn in the basin of the gulf by mixture with the less saline water beneath which it spreads. A chart of the depth to which it would have been necessary to descend to find water as salt at 34 per mille in the gulf in March, 1920, as well as its horizontal limits, irrespective of depth (fig. 100), is therefore instructive as graphic evidence of the recent activity of this movement. The gradient there shown, with upper boundary of 34 per mille water lying 100 meters deeper at the two heads of the two branches of the Y-shaped trough than in the Eastern Channel, is proved the normal state by close correspondence with April (fig. 118) and midsummer (fig. 152). It represents the consumption of this water in the inner parts of the gulf as vertical mixing destroys its identity, and has an important bearing on the circulation of the gulf from this standpoint (p. 849).

Comparison with the corresponding isothermobath (fig. 20) shows that salinity corresponds more closely to the contour of the bottom than to temperature at this season, there being no reason to suppose that water as saline as 34 per mille encroaches at all on Georges Bank in spring. The north-south ridge, which culminates in Cashes Ledge, also influences the salinity of the bottom water more than its temperature.

BOTTOM

The salinity on bottom is interesting chiefly for the biologist who is concerned with the physical conditions to which the bottom fauna is subject. In any small subdivision of the Gulf of Maine this is governed directly by the depth, with the water saltest where deepest; but when the survey is expanded to cover the area as a whole, account must also be taken of the regional differences just described, especially of higher salinities in the eastern side than in the western, and of freshenings of the coastal zone, whether by river freshets or by the Nova Scotian current. Early in the spring, before these last influences have altered the water appreciably from its winter state, the differences in salinity between the two sides of the gulf are widest in the mid depths. Consequently we find the regional variation in bottom salinity is then widest somewhat more than midway down the slopes of the basin, near the 100-meter contour.

In March, 1920, the bottom water of this belt varied in salinity from about 32.3 per mille to 32.5 per mille, along the western and northern margins of the gulf, to about 33.5 per mille on its eastern slope, with a corresponding west-east gradation at greater depths from about 34 per mille at the bottom of the western and northeastern parts of the trough to about 34.8 per mille in the southeastern part, irrespective of slight differences in depth.

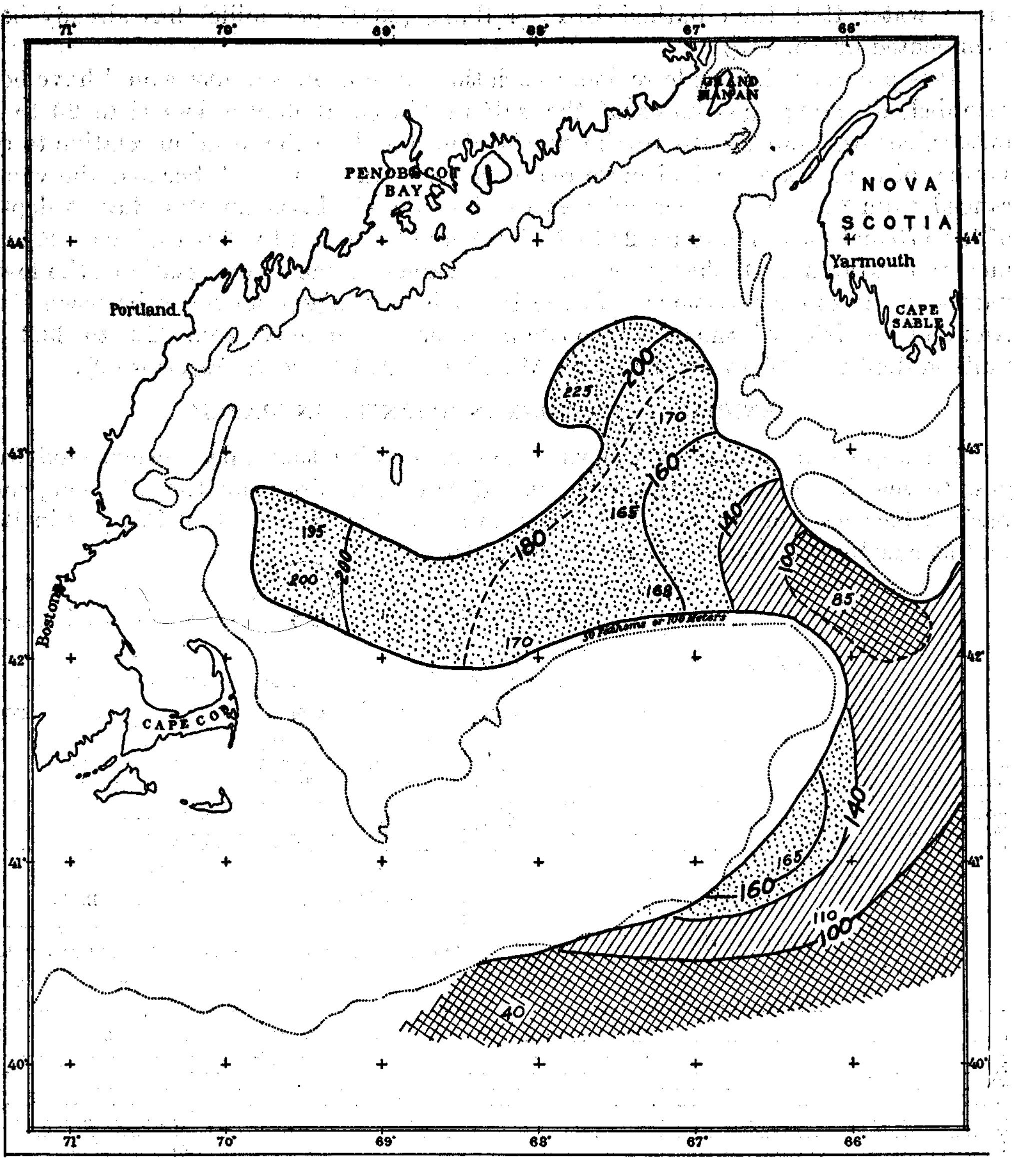

FIG. 100.—Depth below the surface of the isohalobath of 34 per mille, February to March, 1920

Thanks to the vertical homogeneity of the water at this season at depths less than 100 meters, the bottom salinity of the coastal zone was then very uniform from station to station (about 32.3 to 32.6 per mille at most of the stations) in depths of 40 to 100 meters. The bottom water proved equally uniform on Georges Bank, where the extremes recorded (32.6 and 32.8 per mille) were only 0.2 per mille apart in spite of the very considerable area covered by the stations and the variation in depth from 50 to 90 meters.

The contrast between this low bottom salinity on Georges Bank and the more saline water that then bathed Browns Bank (33.02 per mille) has already been commented on (p. 719).

It is probable that wide regional variations in bottom salinity would have been recorded all along the shores of the gulf in March at depths less than 20 to 30 meters, corresponding both to the precise depth and to the location relative to the sources of land drainage, had more readings been taken so shoal, because the values ranged from 32.3 to 33.1 per mille at the bottom of Massachusetts Bay at depths of 12 to 70 meters on February 24 to 28, 1925, and from 32.4 to 33 per mille at 25 to 76 meters on March 10 of that year, the higher values at the deeper stations, the lower values at the shoaler stations. In the Ipswich Bay region, however, between Cape Ann and the Isles of Shoals, the bottom water varied only from 32.9 to 33.2 per mille in depths of 30 to 64 meters on March 12, 1925 (*Fish Hawk* cruise 9).

ANNUAL VARIATIONS IN SALINITY IN MARCH

An approximate idea of the variation in salinity that may be expected from year to year in the gulf at the beginning of March results from the following comparison between the observations taken in its western side by the *Albatross* in 1920 and at nearby locations by the *Halcyon* in 1921:

Depth, meters	Mouth of Massachusetts Bay		Near Isles of Shoals		Off Cape Elizabeth	
	Mar. 1, 1920 20050	Mar. 5, 1921 10511	Mar. 5, 1920 20061	Mar. 5, 1921 10509	Mar. 4, 1920 20059	Mar. 4, 1921 10507
0	32.35	32.64	32.2	32.85	32.09	32.35
40	32.36	32.70	32.34	32.79	[1]32.20	32.47
90					32.32	
100	32.34	32.76	32.41	32.86		32.47
150	32.39	32.70				
175			32.91	32.99		

Depth, meters	Off Seguin Island		Western Basin		
	Mar. 4, 1920 20058	Mar. 4, 1921 10508	Feb. 23, 1920 20049	Mar. 24, 1920 20087	Mar. 5, 1921 10510
0	31.31	32.32	32.52	32.49	32.49
15	32.00	32.30			
30		32.30			
40				32.54	32.47
45	32.34				
50			32.52		
60		32.41			
100			32.54	32.63	32.65
150			33.40	33.53	33.12
200			33.78	34.05	
225					33.08
250				34.22	33.99

[1] Approximately.

These tables show salinities averaging about 0.4 per mille higher in 1921 than in 1920, at depths less than 150 meters along the coastal zone from the mouth of Massachusetts Bay to the neighborhood of Cape Elizabeth; but the readings for the two years were substantially alike off Seguin Island. This also applies to the western basin above the 100-meter level; but 1920 was the salter year there at greater depths, with an annual spread of 0.5 to 1 per mille at 150 to 200 meters.

With so little difference in salinity between the two years it is safe to assume neither was unusually fresh or unusually salt, but that the two together may be assumed to represent a typical Gulf of Maine March.[85]

Judging from one station at the mouth of Massachusetts Bay, with readings of 32.85 per mille at the surface, 32.96 per mille at 25 fathoms, and 33.04 per mille at 45 fathoms (station 10054), the March salinity was about the same in 1913 as in 1921. Again, the salinity of the upper 100 meters of the Fundy Deep was almost precisely the same on March 22, 1920 (station 20079), as on April 9, 1917 (Mavor, 1923); the 150-meter level the same as on February 28 of that year, though 1920 seems to have been slightly the salter at depths greater than 150 meters.

Thus, the March salinity of the gulf showed but little annual variation in the years 1913, 1917, 1920, and 1921, and it is probable that annual differences are smallest at this season. Even in March, however, much wider differences than those just stated are to be expected between springs of heavy or light rainfall and snowfall, or between years when the freshets occur unusually early or unusually late. Fluctuations in the bottom current flowing into the gulf will also be mirrored by salinity.

Hydrometer observations taken in Massachusetts Bay and to the northward of Cape Ann from the *Fish Hawk* on March 10 to 12, 1925, give a hint of this in bottom readings considerably higher than we had previously obtained there at that season—an average of about 33 per mille at 40 to 60 meters depth contrasting with 32.2 to 32.5 per mille for 1920 and 1921. The superficial stratum was likewise slightly more saline in Massachusetts Bay in March, 1925 (32.4 to 32.9 per mille), than in either of the earlier years of record.

VERNAL FRESHENING

The great rush of fresh water that annually pours into the gulf from the land, when the snow melts and brings the rivers into freshet, causes a very decided lowering of salinity contemporaneous with the first signs of vernal warming. The effect of this, first apparent along the western and northern shores of the gulf, had considerably lowered the surface salinity of the superficial stratum off the Kennebec River by March 4 in 1920, a late year (p. 704). The upper 30 to 40 meters of the coast sector between northern Cape Cod and the neighborhood of Mount Desert Island proved decidedly less saline by the 9th to 18th of that April (fig. 101), also, than it had been a month earlier (fig. 91).

Localization of the lowest salinities (in this case <30 per mille) between Cape Elizabeth to the west and Penobscot Bay to the east, up to this date, is evidence that the Kennebec and the Penobscot combined had continued to affect the salinity more than the Saco and the Merrimac did until mid-April in that particular year; but whether a seasonal relationship of this sort is normal, or whether the freshening effect of these two groups of rivers is more nearly simultaneous in most years than

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[85] It will require records for many years to establish the normal state of the waters of the gulf for that month or for any other.

it was in 1920, is yet to be learned. However, observations taken by W. W. Welsh between Cape Ann and Cape Elizabeth, in 1913 (Bigelow, 1914a), favor the first alternative by showing about this same vernal schedule, with the surface off the mouth of the Merrimac saltest at about the end of March and freshening slowly thereafter. Unfortunately there was a gap in his observations for the interval April 5 to 13; but his numerous records on the fishing grounds near the Isles of Shoals revealed a decrease in the surface salinity there from 31.56 per mille on the 13th to 30.03 per mille on the 26th, and to 29.54 per mille on May 5.

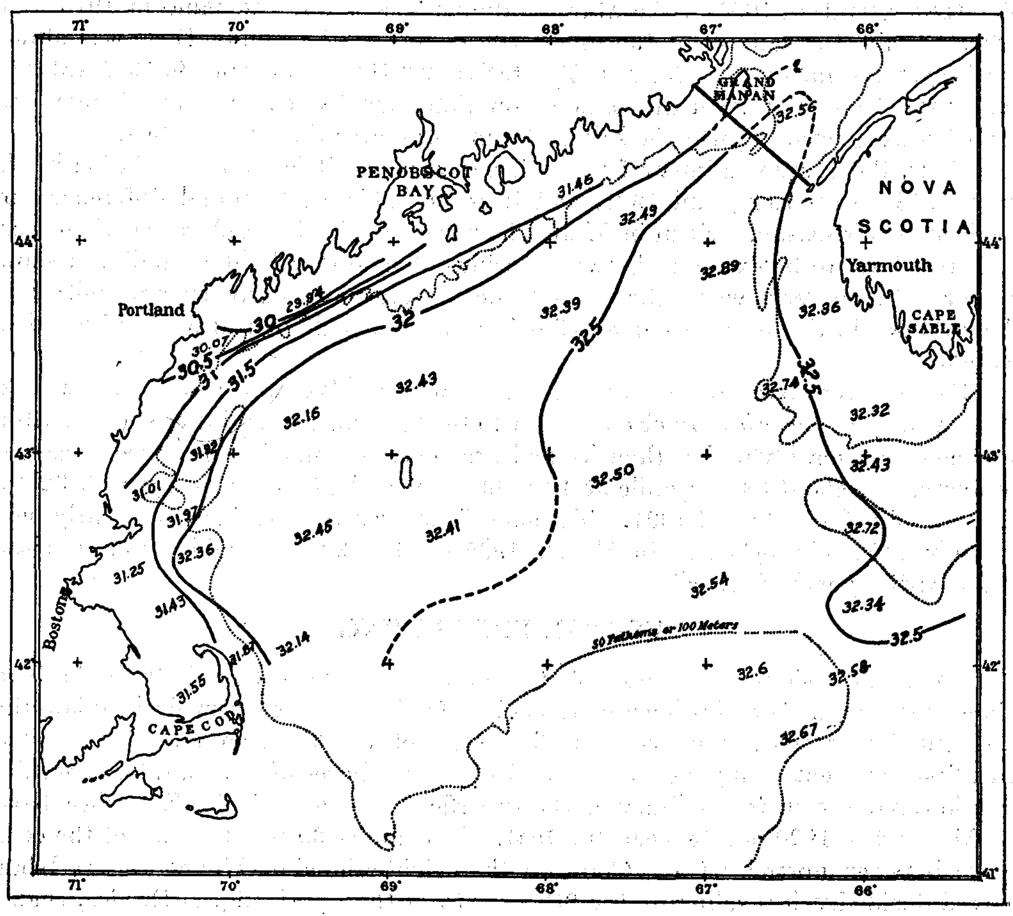

FIG. 101.—Surface salinity, April 6 to 20, 1920 (and for the Bay of Fundy, April 9, 1917; from Mavor, 1923)

The general distribution of salinity is proof enough that the discharges from the great rivers that empty into the Bay of Fundy and along the coast of Maine (St. John, Penobscot, Kennebec, Saco, and Merrimac) turn westward, paralleling the shore and building up the so-called "spring current" reported by local fishermen —not spreading southward toward Nova Scotia. As no large rivers empty into the gulf from that Province, no such extreme vernal freshening of the surface is to be expected along its western shore as characterizes the northern and western margins of the gulf. The minimum for the coastal sector between Cape Sable and St. Marys Bay can not be stated for want of observations close in to the land at the critical season, but may be set (tentatively) at about 31 per mille, contrasting with 28 to 29 per mille in the opposite side of the gulf (p. 702).

In 1925 the surface salinity of the Isles of Shoals–Cape Ann sector had decreased to 28.7 to 29.1 per mille by April 7 to 8, a change of more than 1 per mille since March 12 (*Fish Hawk* cruises 9 and 11). Up to that date, however, freshening from the land had hardly affected the surface at the mouth of Massachusetts Bay, which was still 31.9 to 32 per mille, with 31.2 per mille in its inner waters near Plymouth (*Fish Hawk* stations 10 and 31 to 34, cruise 11). So little change took place in the surface state of the bay during the next two weeks that the *Fish Hawk* again had 31.1 per mille to 32 per mille there on April 21 to 23.

The reason the surface of Massachusetts Bay does not experience a drop in salinity as early or as sudden as the coast sector north of Cape Ann, only a few miles away, is simple: No large streams empty into the bay, so that the only source from which it can receive large volumes of land water are the rivers tributary to more northerly parts of the gulf. Naturally the freshening effect of these is not as pronounced at a distance from their mouths as it is near by, nor is it felt as soon. This explanation is corroborated also by the fact that the lowest salinities recorded for the Massachusetts Bay region for April 21 to 23, 1925, took the form of a tongue extending southward past Cape Ann, obviously with its source to the north—i. e., from the Merrimac (fig. 102).

The general surface chart for April, 1920 (fig. 101), is made one of the most interesting for the year by its demonstration that the freshening effect of the river freshets continues strictly confined to the coastal zone until late in the month and does not spread out over the surface of the gulf generally, as might, perhaps, have been expected. By contrast, the basin of the gulf outside the 100-meter contour alters so little in salinity from March to April that the greatest change there from the one month to the next in 1920 was only about 0.5 per mille for any pair of stations. The surface also remained unaltered over the eastern end of Georges Bank (we have no April data for the western end), where the extreme variation in salinity from March to April of that year was only about 0.1 per mille. Mr. Douthart found a similar gradation (though with actual values 0.5 to 1 per mille higher) on April 27, 1913, from 31.5 in Massachusetts Bay to 33.1 to 33.3 per mille on the southwestern part of the basin and along the northern half of Georges Bank. The contrast in the salinity of the surface water between inshore and offshore stations is greater in April, in fact, than in any other month. On the other hand, the pool of high surface salinity (32.8 per mille) that occupied the southeastern part of the basin of the gulf and the inner end of the Eastern Channel in March, 1920 (p. 704, fig. 91), had been entirely dissipated by the middle of the following month, leaving this whole area uniformly about 32.5 to 32.6 per mille at the surface; but in its stead the surface salinity at one station in the eastern side of the basin, off Lurcher Shoal, had been increased to an equally high value (32.89 per mille) by some local disturbance of water.

The discovery of these pools of high salinity in different localities in different months—one of them, at least, short lived—is more interesting than the slight actual alteration in value might suggest, as evidence that phenomena of this sort may be expected to develop temporarily anywhere in the eastern side of the gulf during the season of the year when the vertical stability of the water is slight.

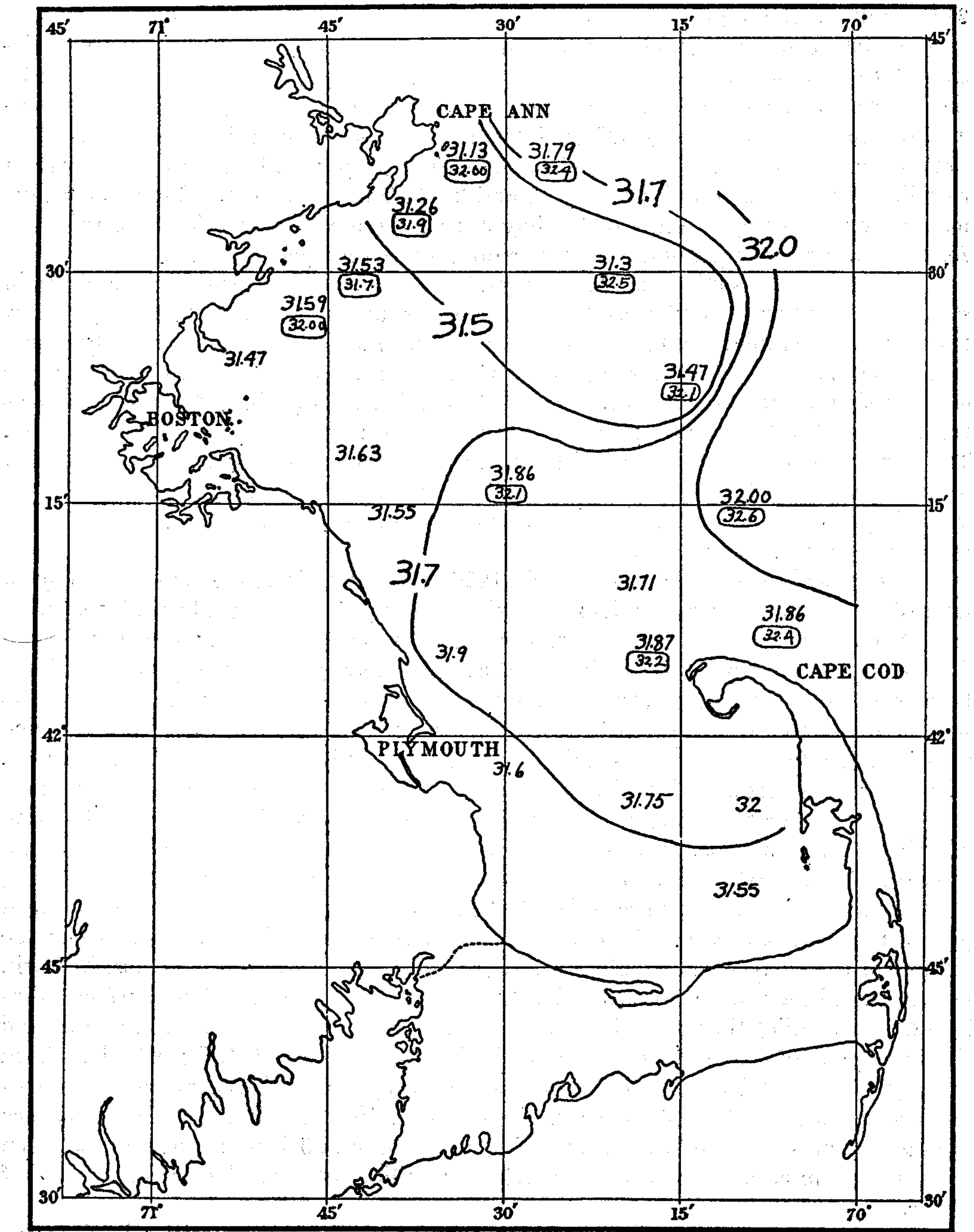

FIG. 102.—Salinity of Massachusetts Bay at the surface (plain figures) and at 40 meters (encircled figures), April 21 to 23, 1925

Changes in the salinity of the surface water off the western coast of Nova Scotia from March to April, or to the southward of Cape Sable, demand attention, because any considerable movement of the cold, comparatively fresh water of the Nova Scotian current past Cape Sable from the eastward would necessarily decrease the salinity of the neighboring parts of the Gulf of Maine, just as it retards the warming of the surface there (p. 558). In 1920 no evidence of this appears in the distribution of salinity up to the end of April. In fact, the surface was actually slightly salter on Browns Bank, near Seal Island, and off Yarmouth, Nova Scotia, on April 13 to 16 (stations 20102, 20104, and 20106) than it had been on March 13 to 23 (stations 20072, 20084, and 20085), and with no appreciable change in the Northern Channel.[86]

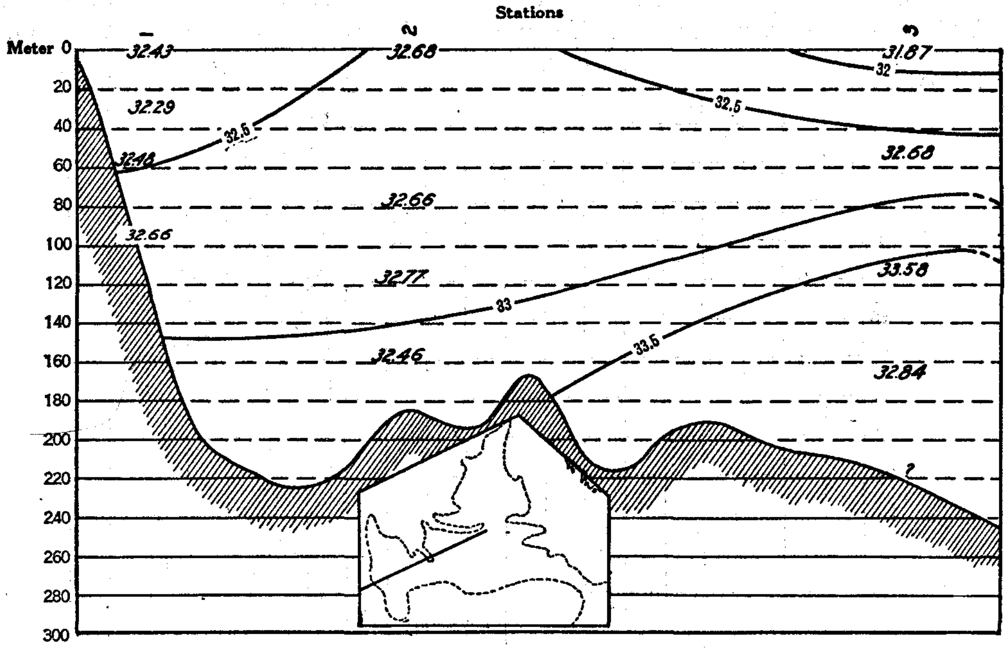

FIG. 103.—Salinity profile running eastward from Cape Cod, March 28 to 29, 1919 (ice patrol stations 1 to 3)

In 1919, however, the very low temperature recorded in the eastern side of the basin by the Ice Patrol cutter on March 29 (p. 553) had its counterpart in surface salinity considerably lower (31.87 per mille) than that of the western side of the gulf at the time (32.4 to 32.7 per mille; fig. 103). Judging from the geographic location, this can hardly have drawn from any source other than the Nova Scotian current.

Unfortunately no observations were made on the salinity of the northern parts of the gulf during the spring of 1919, so that it is impossible to state how much this Nova Scotian water had affected the surface salinity in that direction, nor (for the same reason) how far it spread over the offshore banks to the southwest during that spring. Probably, however, it reached its farthest westward expansion by the last of that March or soon after, because a second profile of the gulf crossed the isohaline for 32 per mille at about the same longitude a month later (Ice Patrol stations 19 to 22, p. 997). A considerable amount of water of low salinity must therefore

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[86] No observations were taken in the gulf during the summer of 1920.

have continued to drift westward past Cape Sable during this 4-week interval to maintain so almost uniformly low a salinity (31.7 per mille) so far westward.

The data for 1919 and 1920 thus show a considerable yearly variation in the date when the Nova Scotian current most influences the salinity of the Gulf of Maine—a variation associated with the factors that govern the general scheme of circulation along the Nova Scotian shelf to the eastward, and with the outflow from the Gulf of St. Lawrence (p. 830). Therefore, it does not necessarily follow that if the gulf is early or late in showing the freshening effects of the freshets from its tributary rivers in any given year the cycle of salinity will be correspondingly early or late in its eastern side.

The lowest value to which Nova Scotian water may reduce the salinity of the surface of the eastern side of the gulf can not yet be stated; but on theoretic grounds it is probable that the value recorded for April 28, 1919 (about 31.7 per mille), is near the minimum, because any flow into the gulf from the eastward necessarily crosses the coastwise bank off Cape Sable, where tidal churning is so active that the fresher current must constantly mix with salter water and so, to a considerable extent, lose its distinguishing character.

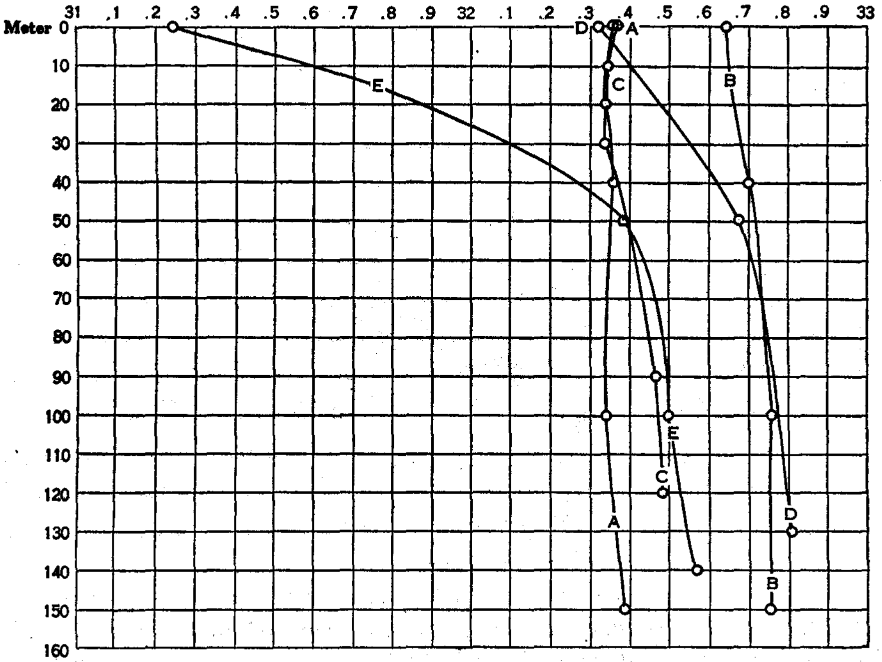

FIG. 104.—Vertical distribution of salinity off Gloucester on March 1, 1920 (A, station 20050), and March 5, 1921 (B, station 10511); for April 9, 1920 (C, station 20090); also for May 4 and August 31, 1915 (D, station 10266, and E, station 10306)

VERTICAL DISTRIBUTION OF SALINITY IN APRIL

Graphs for successive dates in the spring of 1920 (figs. 104 to 109, 112–114) illustrate the effect that the vernal outpouring from the rivers exerts on the deeper strata next the land during the last weeks of March and first half of April.

In the western side of the gulf the seasonal alteration decreases progressively as the depth increases, to *nil* at a depth of 80 meters off Cape Cod (fig. 106). If Massachusetts Bay can be taken as representative of this side of the gulf, the freshening effect penetrated somewhat deeper or somewhat more rapidly in 1925, when the bottom water in 70 meters' depth was about 0.5 per mille less saline at one station on April 23 (*Fish Hawk* station 18A) than it had been on March 10.

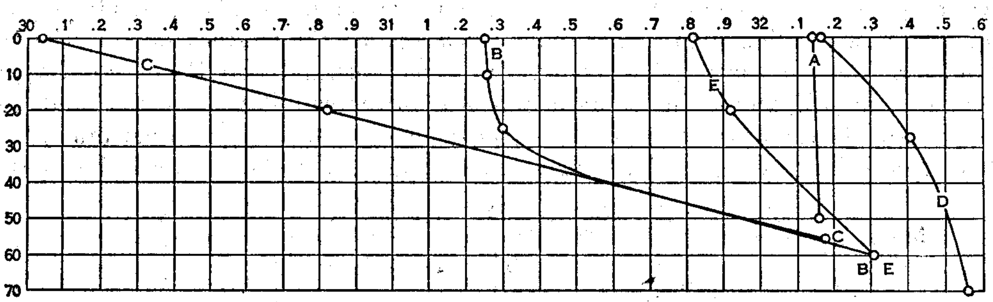

FIG. 105.—Vertical distribution of salinity off Boston Harbor at various seasons. A, March 5, 1920 (station 20062); B, April 6, 1920 (station 20089); C, May 16, 1920 (station 20123); D, August 20, 1913 (station 10106); E, December 29, 1920 (station 10488)

Wide local variation is to be expected in this respect, depending on how actively the water is stirred by waves and tides, in even as small an area as Massachusetts Bay, where a vertical range of about 0.6 per mille developed in the central part by April 22 to 23 in 1925, though the waters of Cape Cod Bay still continued nearly homogeneous, vertically, but about 1 per mille less saline than they had been on March 10.

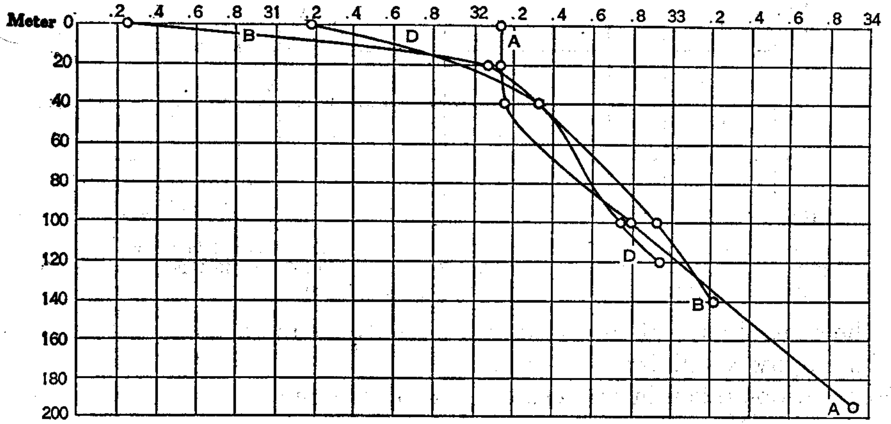

FIG. 106.—Vertical distribution of salinity off northern Cape Cod in various months. A, April 18, 1920 (station 20116); B, May 16, 1920 (station 20125); D, July 14 1913 (station 10213)

The freshening effect of the discharge from the Merrimac and Saco Rivers seems also to have penetrated down to a considerable depth into the gulf during April of 1913 (stations 8 and 18, William Welsh; p. 981). In 1920, however, this freshening was confined to the upper 60 meters near Seguin Island and to the upper 35 to 40 meters near Mount Desert Island (fig. 107), up to the middle of April.

The upwellings caused by offshore winds, which temporarily raise the salinity of the surface along the western shores of the gulf (p. 709), exert a corresponding effect on the deeper strata as water moves over the bottom from greater depths farther out at sea. Observations taken off the Isles of Shoals on April 16 and 22, 1913, illustrate this by an increase in the salinity of the whole column.

Any April profile running out from the northern or western shore of the gulf will show the effect of the vernal runoff of land water by a band of low surface salinity at the inshore end, broader or narrower and with actual values higher or lower, according to the exact locality. Profiles from Massachusetts Bay (fig. 110) show it as a wedge less saline than 32 per mille based against the western slope of the gulf. Profiles normal to the coast anywhere between Portland and Penobscot Bay, for this same month, would have cut across still lower salinities next the land. Its direct result is the development of a stratum less saline than 32.5 per mille, 50 to 60 meters thick, by April, blanketing the surface from the western shores right out to the central part of the basin, where only a superficial layer, 10 meters or so thick, has so low a salinity in March.

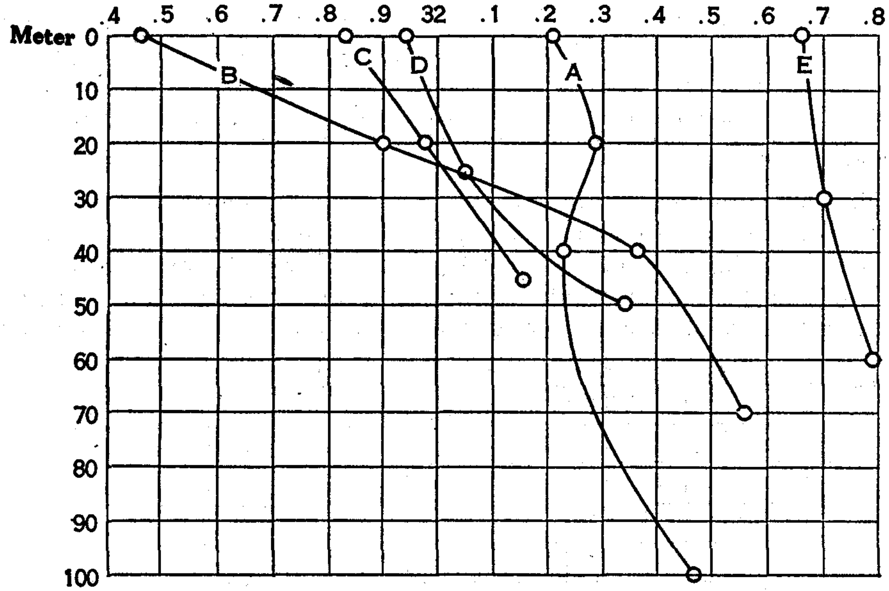

FIG. 107.—Vertical distribution of salinity a few miles off Mount Desert Island in various months. A, March 3, 1920 (station 20056); B, April 12, 1920 (station 20099); C, July 19, 1915 (station 10302); D, August 18, 1915 (station 10305); E, October 9, 1915 (station 10328)

Observations taken in the eastern side of the gulf at any time during the few weeks when the Nova Scotian current is bringing a large volume of comparatively fresh water past Cape Sable would show a similiar wedge of low salinity, basing on German Bank and extending out over the eastern side of the basin. This state is illustrated on the profile for 1919 (fig. 103). In 1920, however, neither of our spring cruises coincided with this event, so that the isohalines projected in east-west profile inclose homogeneous water over German Bank (fig. 110), just as they do at other times of year.

Along the western coast of Nova Scotia (figs. 109 and 110) the tides stir the water so thoroughly that vernal alteration at first proceeds at a nearly uniform rate,

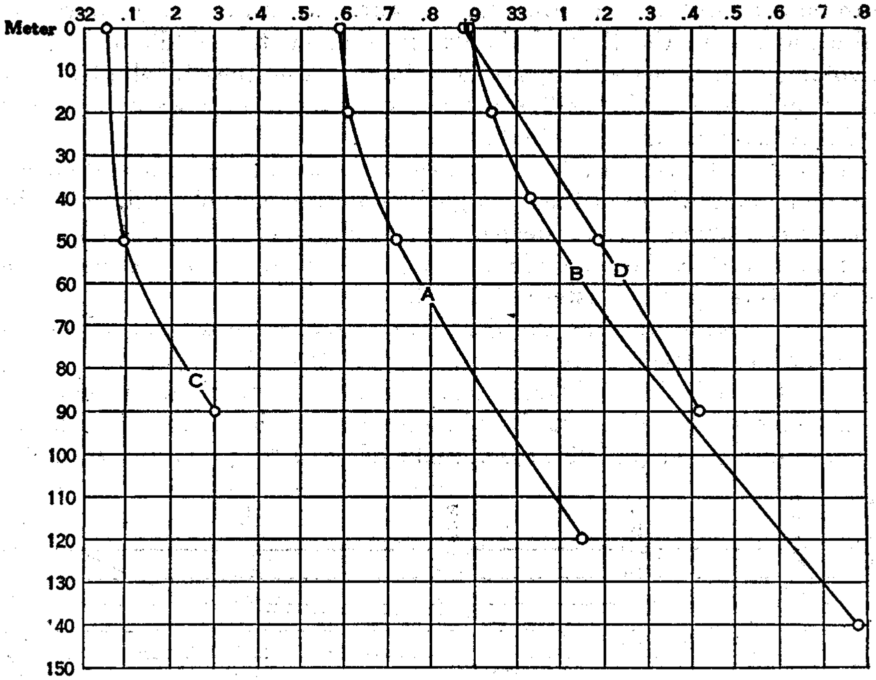

FIG. 108.—Vertical distribution of salinity near Lurcher Shoal. A, March 23, 1920 (station 20082); B, April 12, 1920 (station 20101); C, May 10, 1915 (station 10272); D, September 7, 1915 (station 10315)

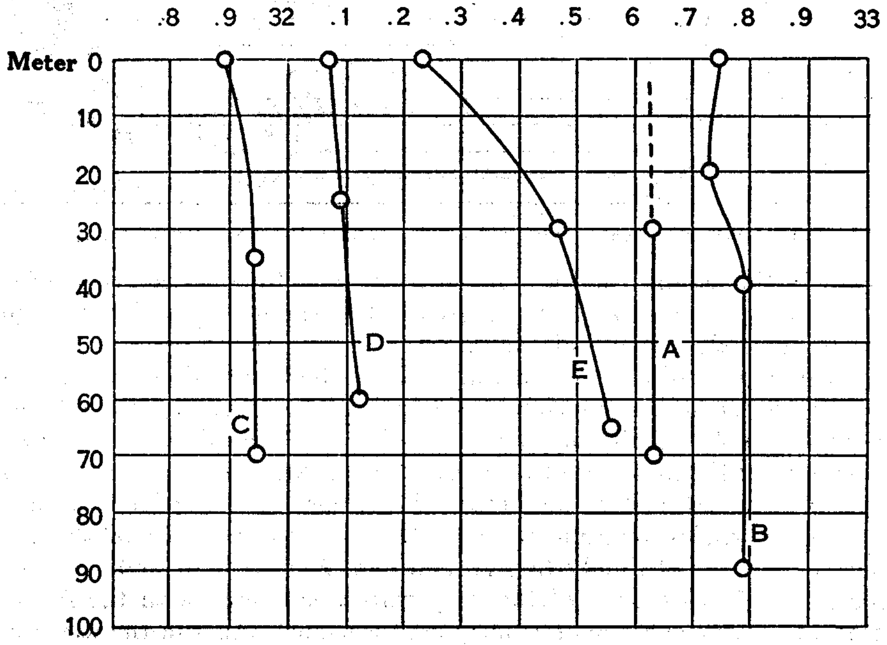

FIG. 109.—Vertical distribution of salinity on German Bank. A, March 23, 1920 (station 20085); B, April 15, 1920 (station 20103); C, May 7, 1915 (station 10271); D, June 19, 1915 (station 10290); E, September 1, 1915 (10311)

surface to bottom, out to the 100-meter contour. Mavor's (1923) tables show that this is also the case in the Bay of Fundy up to about the middle of April, when so great a volume of fresh water empties into the bay from the St. John River and from its other tributaries that in 1917 the salinity of the surface water of the center of the bay fell to 29.2 per mille at the first of May.

The effects of the vernal freshening just described do not penetrate deeper than 80 to 100 meters anywhere in the open gulf before the end of April, unless in exceptional years; consequently, the deeper waters either continue virtually unchanged through that month or become slightly more saline by incorporation of the water that moves in through the Eastern Channel.

During the spring of 1913 the deepest strata of Massachusetts Bay continued to show this comparative constancy up to April 3 (fig. 111; Bigelow, 1914a, p. 392), although the surface had already freshened by about 0.5 per mille; and while the whole column of water in Massachusetts Bay freshened appreciably from March 10 to April 23 in 1925, as just noted (p. 729), the vernal cycle of 1920 paralleled that of 1913 by an increase in the salinity of the bottom water over the gulf as a whole from mid-March to mid-April at depths greater than 100 meters, except in its southeastern parts, where little alteration took place.

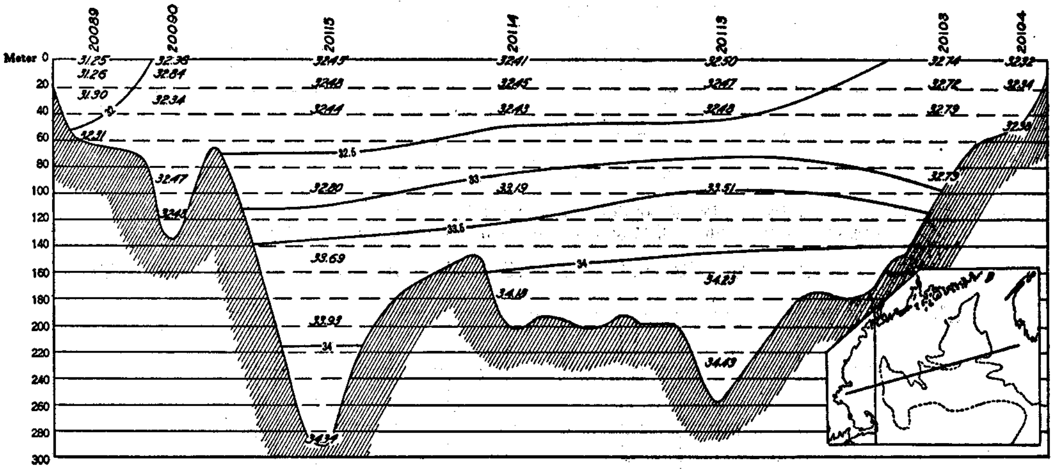

FIG. 110.—Salinity profile running eastward from Massachusetts Bay to the offing of Cape Sable, April 6 to 18, 1920

Thus the salinity of the bottom water of the bowl off Gloucester increased by about 0.1 to 0.2 per mille from March 1 to April 9 of that year. While little alteration took place in the salinity of the western side of the basin at depths greater than 100 meters during the first half of that April (fig. 112), that of the central part rose by 1.1 per mille at 180 meters (fig. 113), with a corresponding increase of 0.2 to 1 per mille for the whole column of water in the northeastern part of the trough off the mouth of the Bay of Fundy (fig. 114, stations 20081 and 20100).

As a result of this salting of the deep water, combined with the freshening of the surface, the vertical range of salinity becomes much wider in the western part of the gulf by mid-April than it is during the first half of March. Off northern Cape Cod, for example, the spread between surface and bottom values increased from about 0.4 per mille on March 24, 1920, to about 0.9 per mille on April 19 (fig. 106), and to 0.6 per mille on April 6 off Boston Harbor, where the whole column of water had been virtually uniform, surface to bottom, on March 5. However, the curves for the several pairs of stations remained more nearly parallel from March to April in the eastern side of the gulf, although the salinity had increased considerably in the meantime (figs. 108, 114).

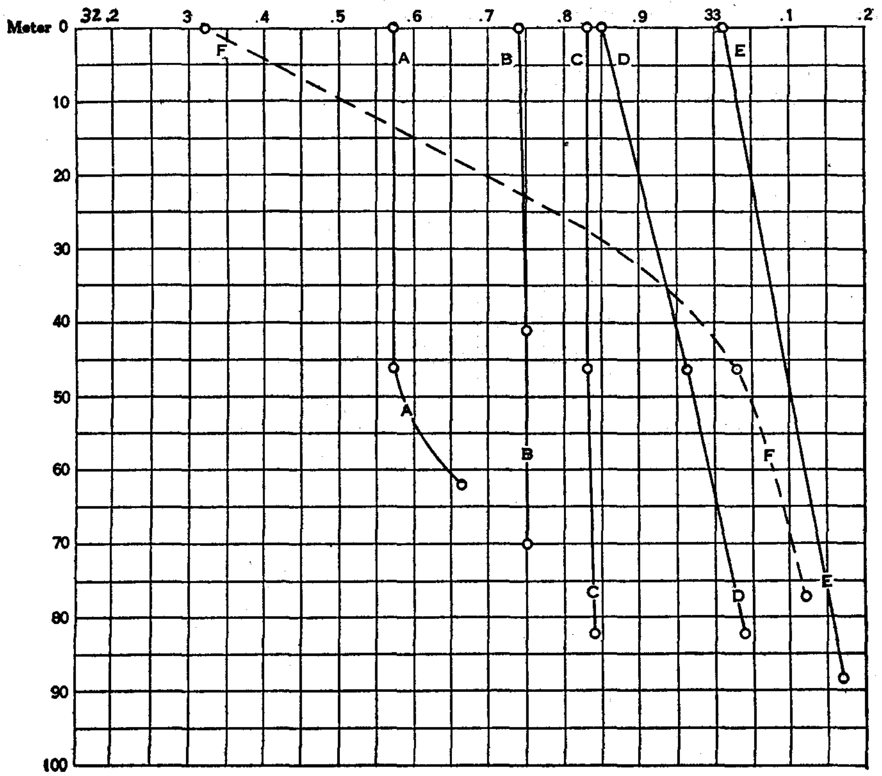

FIG. 111.—Vertical distribution of salinity at the mouth of Massachusetts Bay, off Gloucester, during the winter and spring of 1912–1913. A, November 20 (station 10047); B, December 23 (station 10049); C, February 13 (station 10053); D, March 4 (station 10054); E, March 19 (W. W. Welsh station 1) F April 3 (station 10055)

SALINITY IN HORIZONTAL PROJECTION BELOW THE SURFACE IN APRIL

The deeper down in the gulf the salinity is charted in horizontal projection for April, the more nearly does it parallel the winter state. Thus the band of low salinity (31 per mille) so conspicuous along the northwestern margin of the gulf on the surface chart for mid-April (fig. 101) is but faintly suggested at 40 meters (fig. 115), where the recorded values were only slightly lower (32 to 32.3 per mille) than in the center of the basin (32.4 to 32.5 per mille) and closely reproduced the March state (fig. 93). How little effect the vernal inrush of river water exerts on the deep strata of the Massachusetts Bay region before the end of April appears from the deep readings taken there in the third week of the month in 1925 (fig. 102).

An interesting change did take place, however, at the 40-meter level in the eastern side of the gulf from March to April in 1920, the pool of saltest (33 per mille) water (p. 708) having drifted northward, so to speak, from the offing of German Bank to the offing of Lurcher Shoal, but having been cut off, at the same time, from the still more saline water outside the edge of the continent by a considerable decrease in the salinity of the southeastern part of the basin and of the Eastern Channel (cf. fig. 115 with fig. 93). This change, however, did not result from an expansion of the cold Nova Scotian water in this direction because accompanied by an increase in temperature.

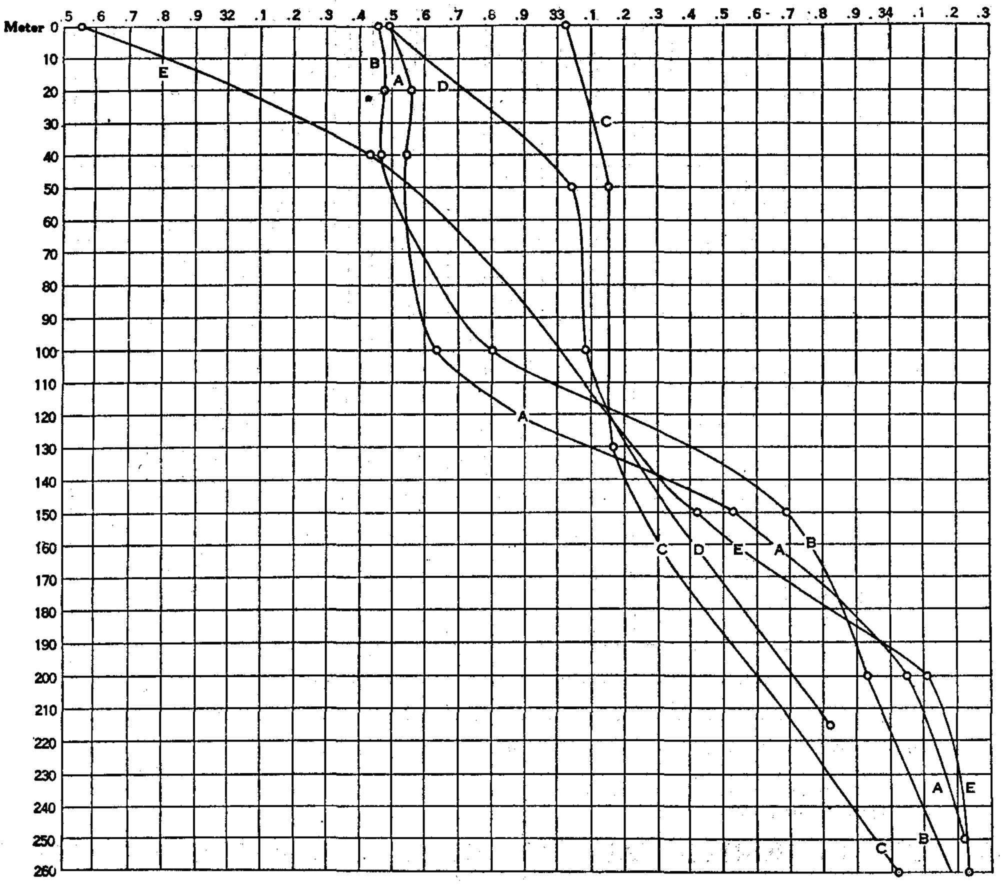

FIG. 112.—Vertical distribution of salinity in the western arm of the basin of the gulf off Cape Ann. A, March 24, 1920 (station 20087); B, April 18, 1920 (station 20115); C, May 5, 1915 (station 10267); D, June 26, 1915 (station 10299); E, August 22, 1914 (station 10254)

The most obvious effect of the increase that takes place in the salinity of the deeper levels of the gulf during the spring is to carry the isohalines for successive values westward, until the entire basin at the 100-meter level was made more saline than 32.6 per mille by mid-April in 1920, and most of its area more saline than 33 per mille (cf. fig. 116 with fig. 94). As a result, the west-east gradation in salinity decreased, and at the same time water more saline than 33 per mille flooded in toward the southeastern slope of Georges Bank, obliterating the fresher pool that had occupied that situation in March.

On the other hand the water more saline than 34 per mille that had occupied the eastern side of the Eastern Channel in March had sunk deeper than 100 meters by mid-April, with a corresponding decrease in temperature (p. 553).

This general and rather complex seasonal alteration is illustrated more graphically in profile by the flooding of the entire basin with water more saline than 34 per mille, at depths greater than 140 to 160 meters, from March to April, on a line running southward from Mount Desert (fig. 117). This was accompanied by a flattening out of the undulations that had marked the upper boundary of the bottom layer of high salinity in March (p. 717), the isohalines for 33 to 33.5 per mille sinking in the eastern side of the basin and rising in the western.

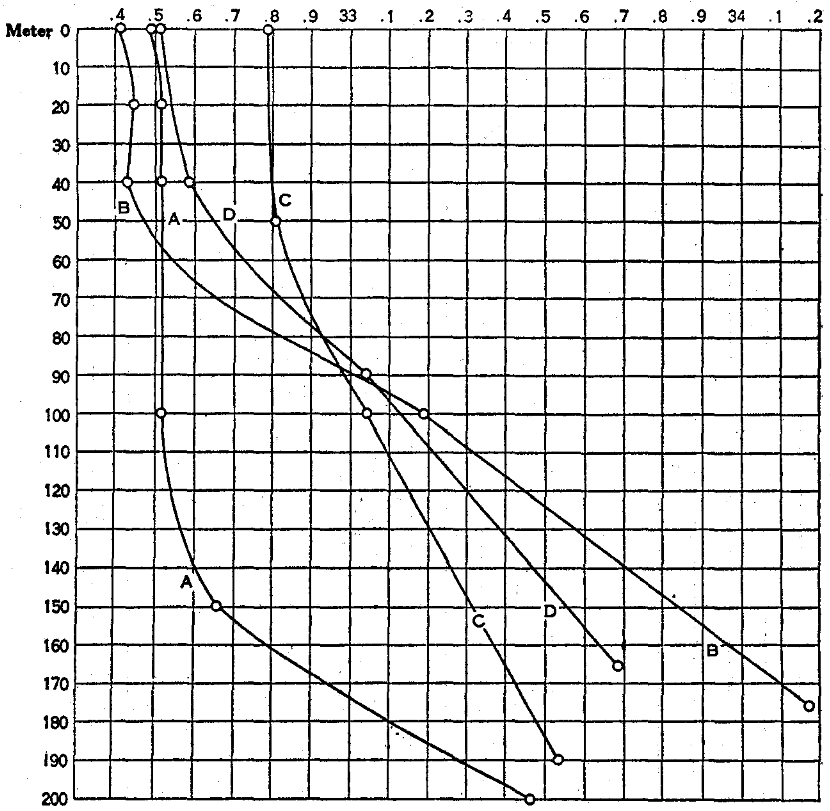

FIG. 113.—Vertical distribution of salinity in the center of the gulf near Cashes Ledge. A, March 2, 1920 (station 20052); B, April 16, 1920 (station 20114); C, May 5, 1915 (station 10268); D, September 1, 1915 (station 10308)

However, the level where the salinity altered most rapidly with increasing depth remained approximately constant in the basin from March to April in 1920, centering at about 150 meters; the limits of salinity within which the gradient was most rapid (33 to 33.5 per mille) also remained constant, and the banking up of the saltest water of the basin (34.5 per mille) against the slope of German Bank persisted.

It is unfortunate that no observations were taken in the Bay of Fundy in April, 1920; lacking such, it is impossible to state whether or not this expansion of water of high salinity involved the bay. In 1917 an alteration of the opposite sort took place there from February to April, evidence that the incorporation of fresher water from above was more than sufficient to counteract the effect of any indraft at the bottom.

A cross-section of the Eastern Channel for April (stations 20106 to 20108) would reproduce the March picture (fig. 99) so closely that it need not be reproduced here. The only difference worth comment is that the whole column of water on Browns Bank had become vertically equalized during the interval at a salinity (32.7 per mille) about equaling the mean of the corresponding stratum over the channel, evidence that no important overflow had taken place over the bottom of the bank meantime, either from the west or from the east. The distribution of salinity in the trough of the channel also points to a slackening of the inflow along the bottom

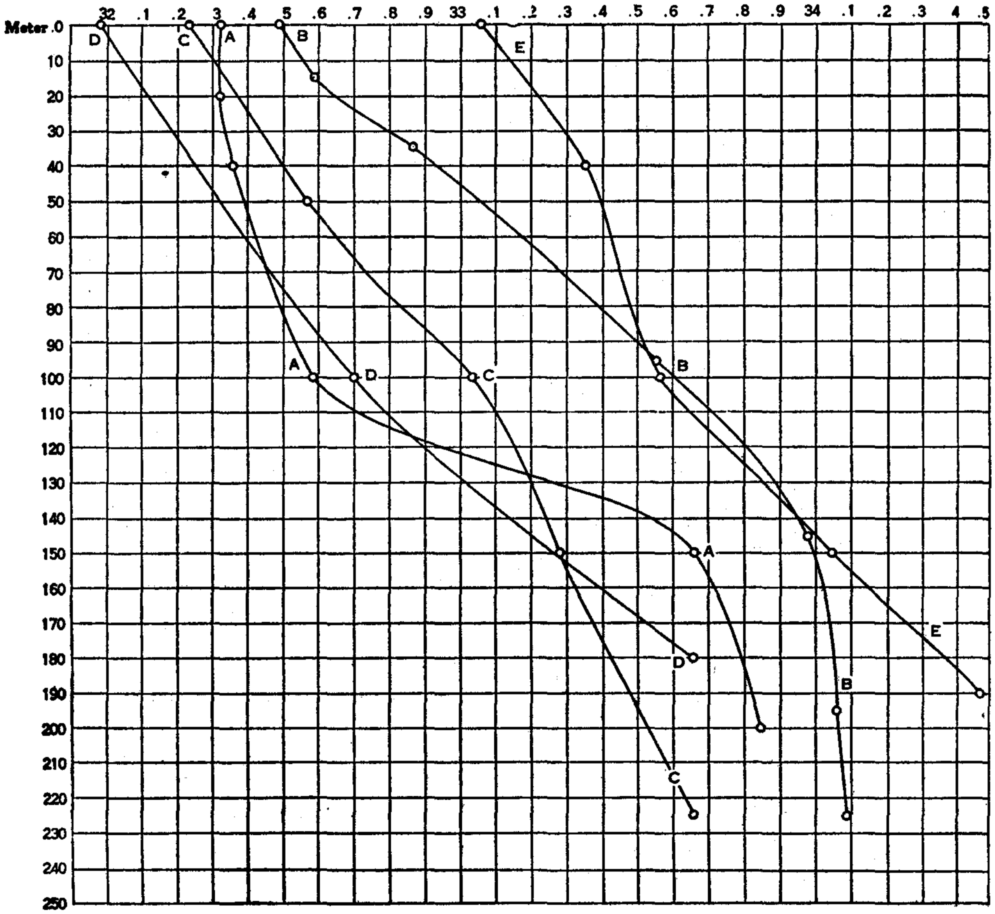

FIG. 114.—Vertical distribution of salinity in the northeastern corner of the gulf. A, March 22, 1920 (station 20081); B, April 12, 1920 (station 20100); C, May 10, 1915 (station 10273); D, June 10, 1915 (station 10283); E, August 12, 1914 (station 10246)

from March, when the saltest water was definitely banked up against its right-hand wall (fig. 99), to April, when the data for stations 20107 and 20108 gave little evidence of this, though the salinity of the water over the slope of Georges Bank, had continued almost unaltered.

The course of events in the deeper strata of the gulf may then be reconstructed as follows for the period March to April of 1920: The presence of a much greater volume of water more saline than 34 per mille in April than in March proves an active pulse inward along the floor of the Eastern Channel, during the first part of the period. This indraft not only effected a considerable increase in the salinity of the bottom water of the basin of the gulf, but resulted in a wide expansion of the area occupied by water more saline than 34 per mille (cf. fig. 118 with fig. 100), as well as raising its upper boundary closer to the surface.

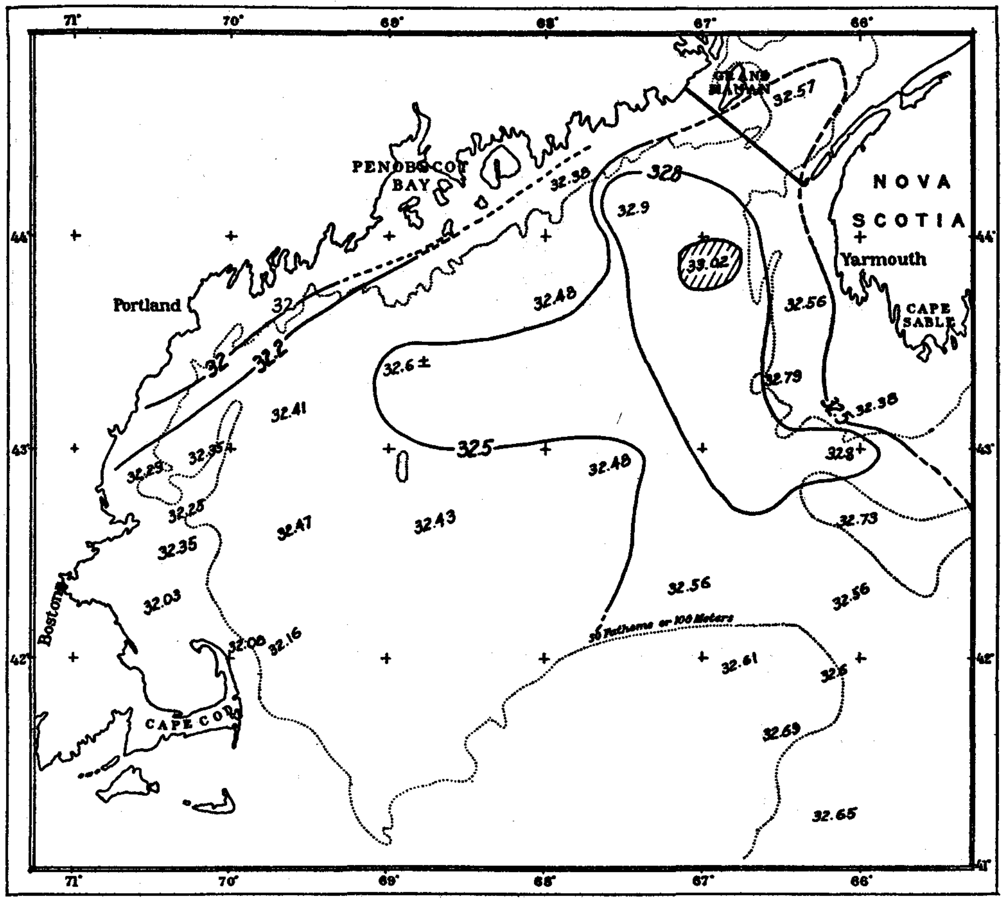

FIG. 115.—Salinity at a depth of 40 meters, April, 1920

The state of the gulf in April, 1920, added to the data for the summer months, makes it almost certain that this 34 per mille water never overflows the coastal slope above the 100-meter contour within the gulf; seldom, if ever, above the 200-meter level in its western side. The extensive, plateaulike elevation of the bottom in the offing of Penobscot Bay, intermediate in depth between these two levels, likewise rises above this highly saline bottom water, although the latter approaches closer than this to the surface in the eastern side of the gulf.

In 1920 the inflowing bottom current slackened at least as early as the first part of April, allowing the horizontal equalization of the water of the basin, just described, and its vertical equalization on Browns Bank; but the general anticlockwise circulation of the gulf continued to carry the more saline water around the basin, thus increasing the salinity of its western side and lessening the regional variations of salinity. On the other hand, the southern side of the Gulf of Maine eddy brought water of comparatively low salinity out of the basin, to the eastern part of Georges Bank, and to that side of the Eastern Channel, in the mid-depths. This probably represents the normal course of events, though no doubt the seasonal schedule falls earlier in some years, later in others.

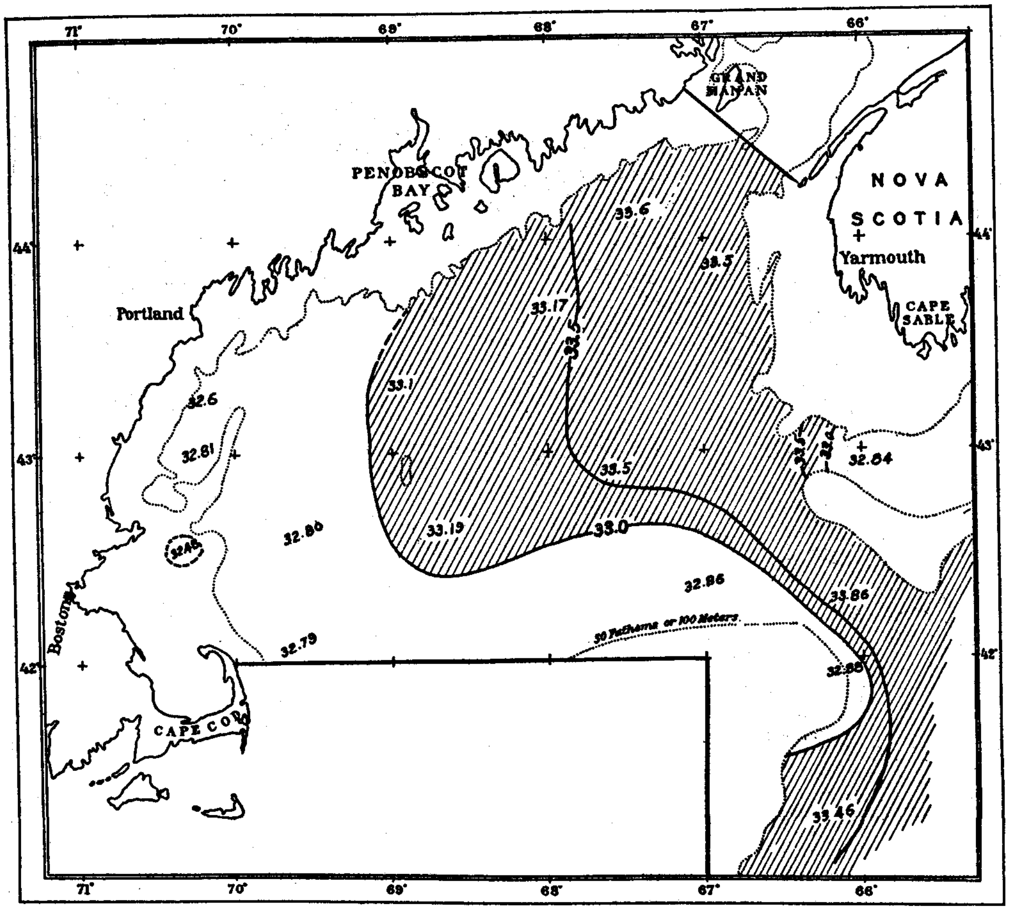

FIG. 116.—Salinity at a depth of 100 meters, April 6 to 20, 1920

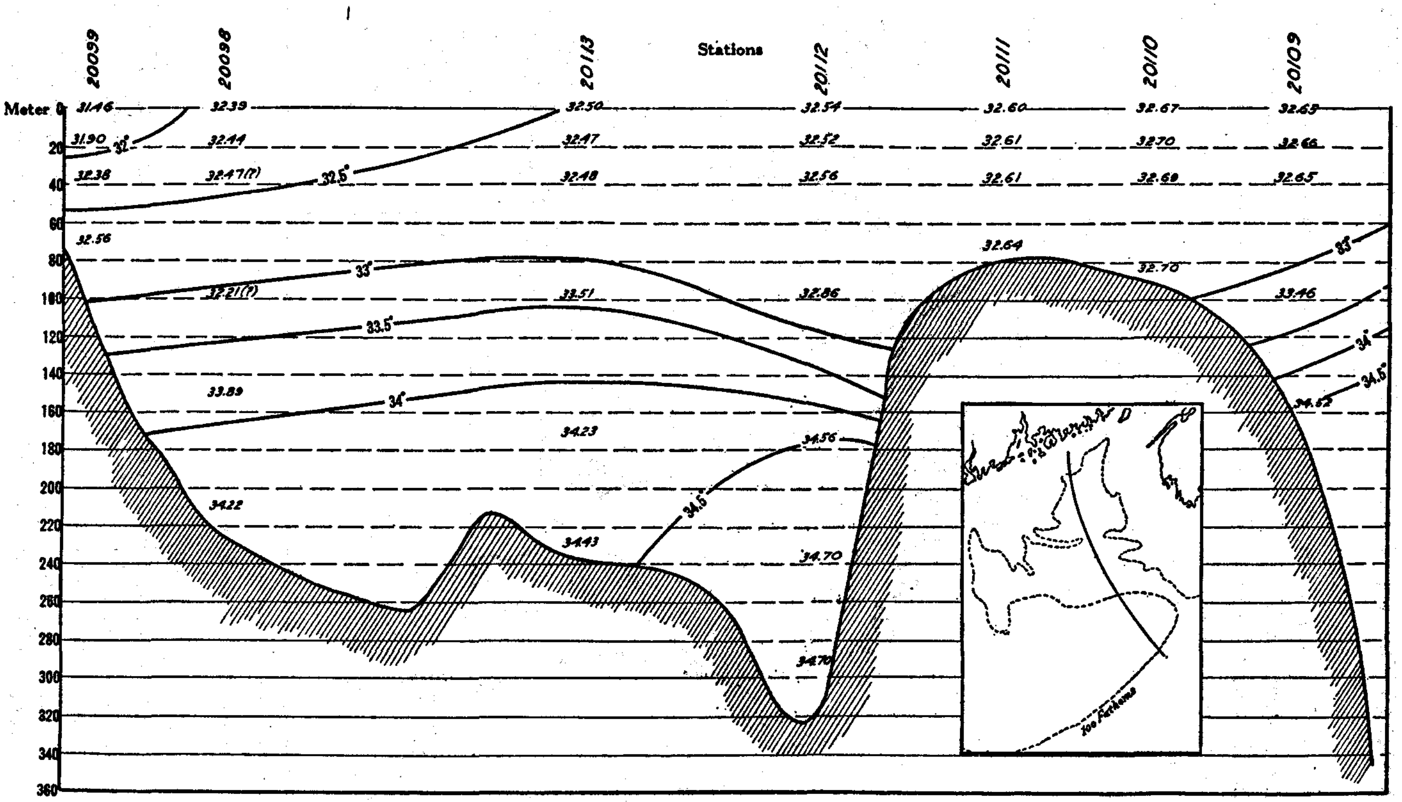

FIG. 117.—Salinity profile, running southward from the offing of Mount Desert Island, across the eastern end of Georges Bank to the continental slope, April 12 to 16, 1920

ANNUAL VARIATION IN THE SALINITY OF THE BOTTOM WATER IN APRIL

The station data for 1920 picture salinity in the deep trough of the Gulf of Maine during a spring when a very considerable volume of water enters via the bottom of the Eastern Channel. Probably the deep water was equally saline in April, 1913, if not more so, when the surface of the southwestern part of the gulf and the whole column of water on Georges Bank were considerable salter than at the corresponding date in 1920 (p. 725). In 1919, however, no salinities higher than 33 per mille were recorded in the bottom of the basin either in March or in April (fig. 103; ice patrol stations 1 to 3 and 19 to 22). This difference is partly to be explained on the assumption that the indraft into the bottom of the gulf ceases during the period (later or earlier in the spring in different years) when the Nova Scotian current is flooding into the upper strata of the gulf from the east. In part, too, the difference between lower salinities in the deeps of the gulf in 1919, than in 1920, can be explained by the fact that the one was an early and the other a tardy season. However, so wide

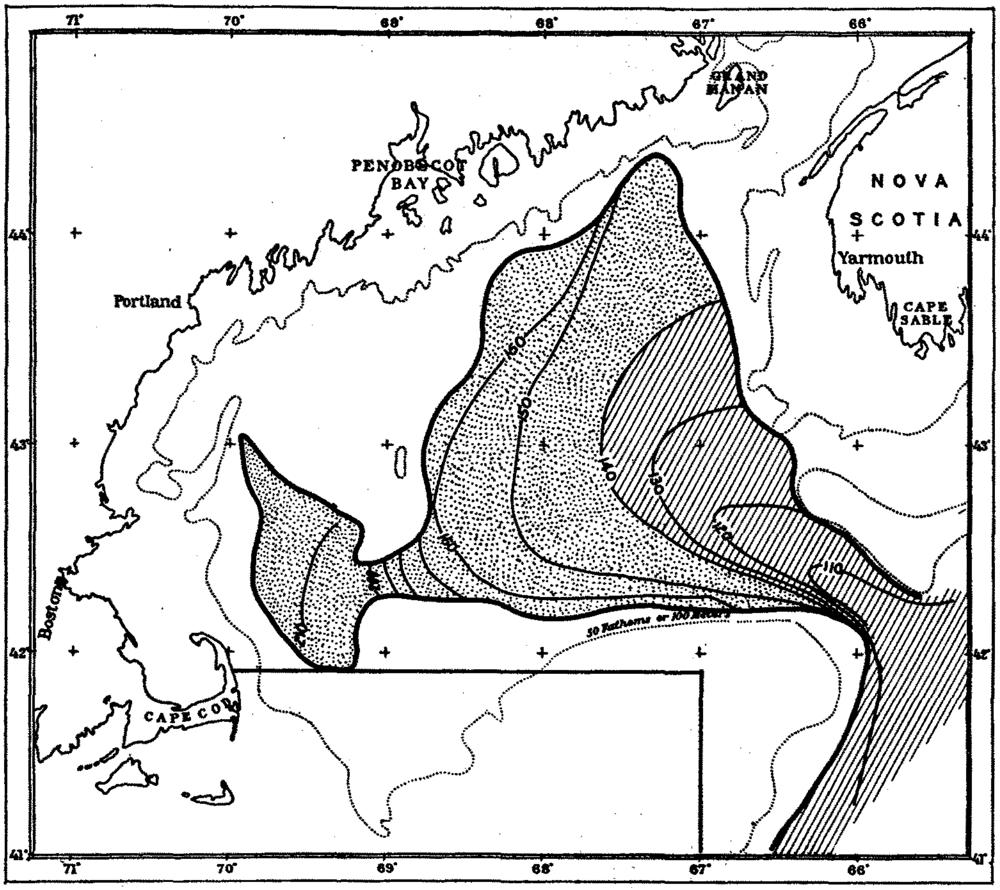

FIG. 118.—Depth below the surface of the isobalobath of 34 per mille, April 6 to 18, 1920

a spread suggests that the bottom of the gulf had actually received much more water via the channel in 1920 than in 1919 during the whole winter.

No cause can yet be assigned to annual differences of this sort, except that they do not result from local influences operative within the gulf, but from the state of the reservoir outside the edge of the continent, which supplies the indraft (p. 848).

SALINITY IN MAY

SURFACE

The salinity of the gulf is especially interesting during the first half of May, because the two most important events in its vernal cycle—freshening of the surface by land water in the western side, and by the Nova Scotian current in the eastern side—culminate then. Unfortunately we have not been able to carry out a general oceanographic survey of the whole area of the gulf in any one May, nor have observations been taken in its southeastern part during that month; but the data for 1913, 1915, 1919, 1920, and 1925 afford a composite picture, which may be taken as representative for normal years because all are fairly consistent.

In 1913 the surface salinity fell to its minimum (29.5 per mille) near the Isles of Shoals about May 5, followed by an increase to 30.9 per mille in the middle of the month; and while a northwest gale on the 10th, 11th, and 12th no doubt was partly responsible for this increase by bringing up more saline water from below, the spring influx of river water had evidently passed its peak by the first week of the month, to be gradually absorbed into the general circulation of the gulf thereafter.

Unfortunately, close comparison is not possible between the years 1913 and 1920, for this region, because the locations of the stations do not coincide, which may cause a very considerable difference in salinity where the precise value depends so much on the proximity to the mouths of rivers. However, the surface again proved much fresher south of the Isles of Shoals on May 7 to 8, 1920 (station 20122, 28.26 per mille), than it had on April 9 (station 20092, 31.01 per mille)—a value even lower than any recorded for 1913.

In 1920, too, the salinity of the surface of the northern part of Massachusetts Bay was almost as low as this on May 4 (stations 20120 and 20121, 29.1 to 29.16 per mille), but apparently this was close to the minimum for the month because followed by a considerable increase at this same general locality to about 29.9 per mille during the next 10 days (stations 20123 and 20124).

In 1925 no observations were taken in Massachusetts Bay during the first 10 days of May, when salinity was probably at its lowest there; and the values recorded there on the 20th to the 22d (fig 119) were so high[87] that some increase may be assumed to have taken place during the second and third weeks of the month in that year, as it certainly did in 1920.

Whether or not the surface salinity of the northern part of Massachusetts Bay fell below 30 per mille for a brief period in 1925, as April readings as low as 29 per mille in Ipswich Bay (p. 725) suggest, water of relatively low salinity was certainly drifting southward past Cape Ann as late as the third week of that May as a tongue less saline than 31.5 per mille directed toward Cape Cod (fig. 119). The

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[87] 31.1 to 31.9 per mille at the surface, averaging 31.6 per mille (*Fish Hawk* cruise 13).

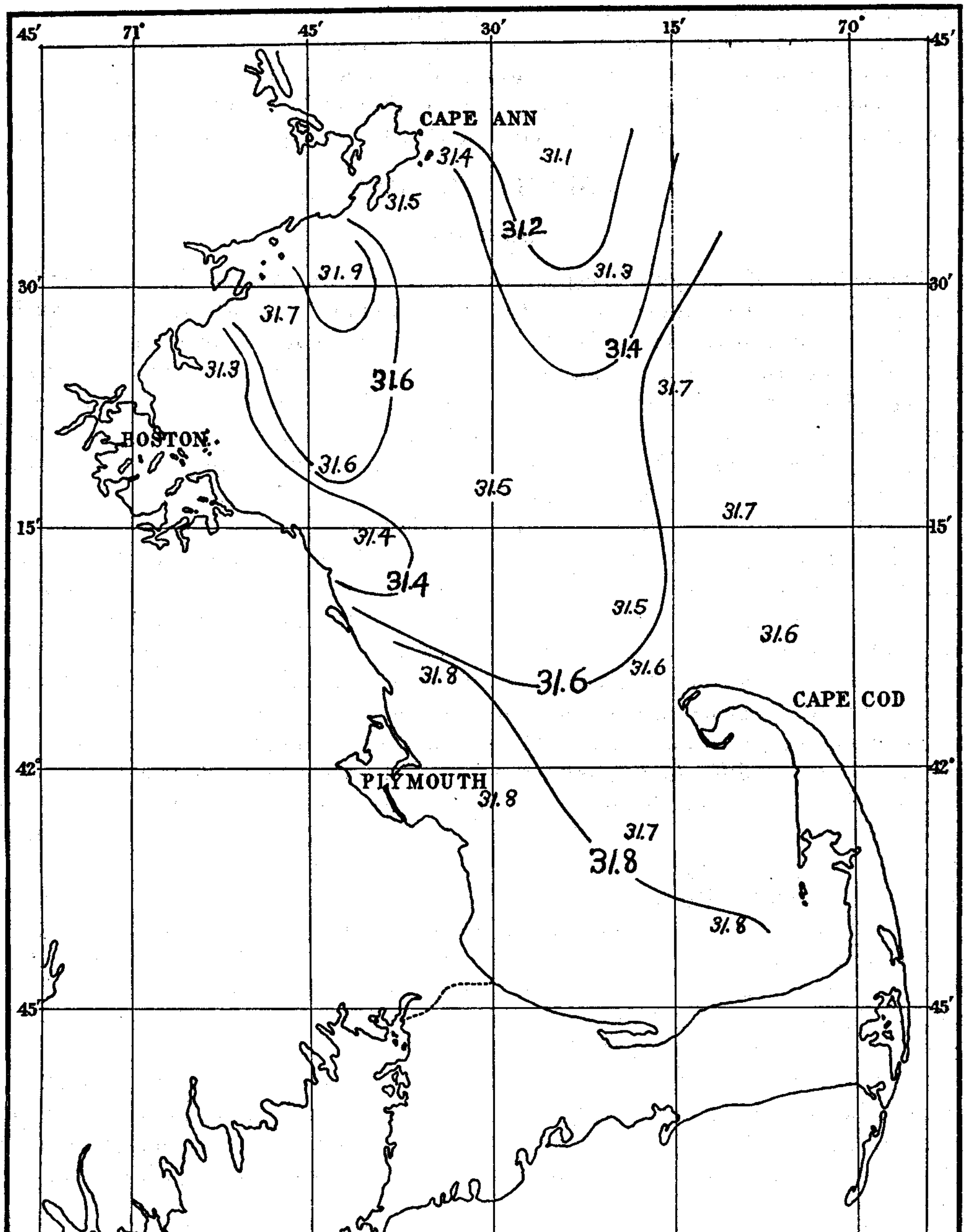

FIG. 119.—Salinity at the surface of Massachusetts Bay, May 20 to 22, 1925, from hydrometer readings

regional uniformity of the inner parts of the bay, where the surface values varied only from 31.3 to 31.8 per mille at 16 stations, also shows how little the discharge from the small streams that empty along the coast line of the bay affects its salinity.

This drift past Cape Ann seems to have hugged the shore of the bay more closely in 1915, because the surface value was much higher at the standard station off Gloucester on May 4 of that year (station 10266, 32.32 per mille), than any other surface reading for the bay in May or in April. Considerable variations are therefore to be expected in the salinity of Massachusetts Bay from one May to the next, both in the precise value and in the date when the water is freshest, reflecting the considerable distance from the freshening sources—the rivers to the northward of Cape Ann. Even in years when the discharge of these rivers is up to normal, and when the freshets fall at the usual season, the southerly drift need only be turned slightly more offshore than usual, by the jutting promontory of Cape Ann, to pass by Massachusetts Bay altogether. In this case the bay would be a sort of backwater, with its surface changing little in salinity from winter through spring. It is probable, therefore, that Massachusetts Bay experiences a wider annual variation in the salinity of its surface waters in spring than any other coast sector of the Gulf of Maine.

The Bay of Fundy illustrates the seasonal cycle where the salinity of the surface reflects the discharge from a large river (here the St. John) close by. Thus, Mavor (1923, p. 375, table 8) records a very sudden decrease in the salinity of the surface, from 32.5 per mille in the middle of April, 1917, to 27.9 per mille on the 4th of May, at a locality between Grand Manan and Nova Scotia, followed, however, by an increase equally rapid to 31.5 per mille by the middle of June. While 1917 is the only spring (and this the only locality) for which the vernal cycle of the open Bay of Fundy has been followed, month by month, it is probable that the seasonal fluctuation outlined by Mavor represents the normal course of events, the surface freshening suddenly when the St. John and the Nova Scotian rivers come into flood, and salting again after the freshets subside as the land water becomes mixed into the bay by the strong tides.

The lowest value to which the surface salinity of the open Gulf of Maine ever falls can not be stated, lacking data near the mouths of the other large rivers at the critical dates in early May. In the Bay of Fundy, 27.9 per mille, just mentioned, is the lowest so far recorded; and salinities equally low are to be expected close along the coast line, thence westward to the Merrimac, though only for a few miles out from the strand, and perhaps hardly outside the outer islands.

The combined chart of surface salinity for the offshore waters of the Gulf for May (fig. 120) shows the freshest water (< 32 per mille) continuing to hug the coast, much as in April (fig. 101); but the great volume of river water that is poured into the gulf at this season so freshens the surface next the shore that the transition to the more saline water offshore is far more abrupt in May than in April; especially off the coast sector between Portland and Cape Ann, where a change of as much as 2 to 3 per mille may be expected at the surface in a distance of 5 to 10 miles, as one runs offshore from the 100-meter contour in May. The development of so fresh a band next the coast admits of but one interpretation—namely, that the non-tidal drift then parallels and closely hugs this part of the shoreline southward as far as

Cape Ann (p. 948), and that land water does not fan out from the coast of Maine or from the Bay of Fundy toward the center of the gulf.

The evidence of salinity is positive in this connection, there being no source for surface water less saline than 30 per mille within the Gulf of Maine other than the rivers tributary to it. Once past Massachusetts Bay, however, the May isohalines for 1920 (stations 20125 to 20129) very clearly show the freshest coast water (32 per mille in this case) spreading out from Cape Cod across the southwestern part of the basin about as far as Georges Bank, which seems to have bounded it at the time in this direction (fig. 120).

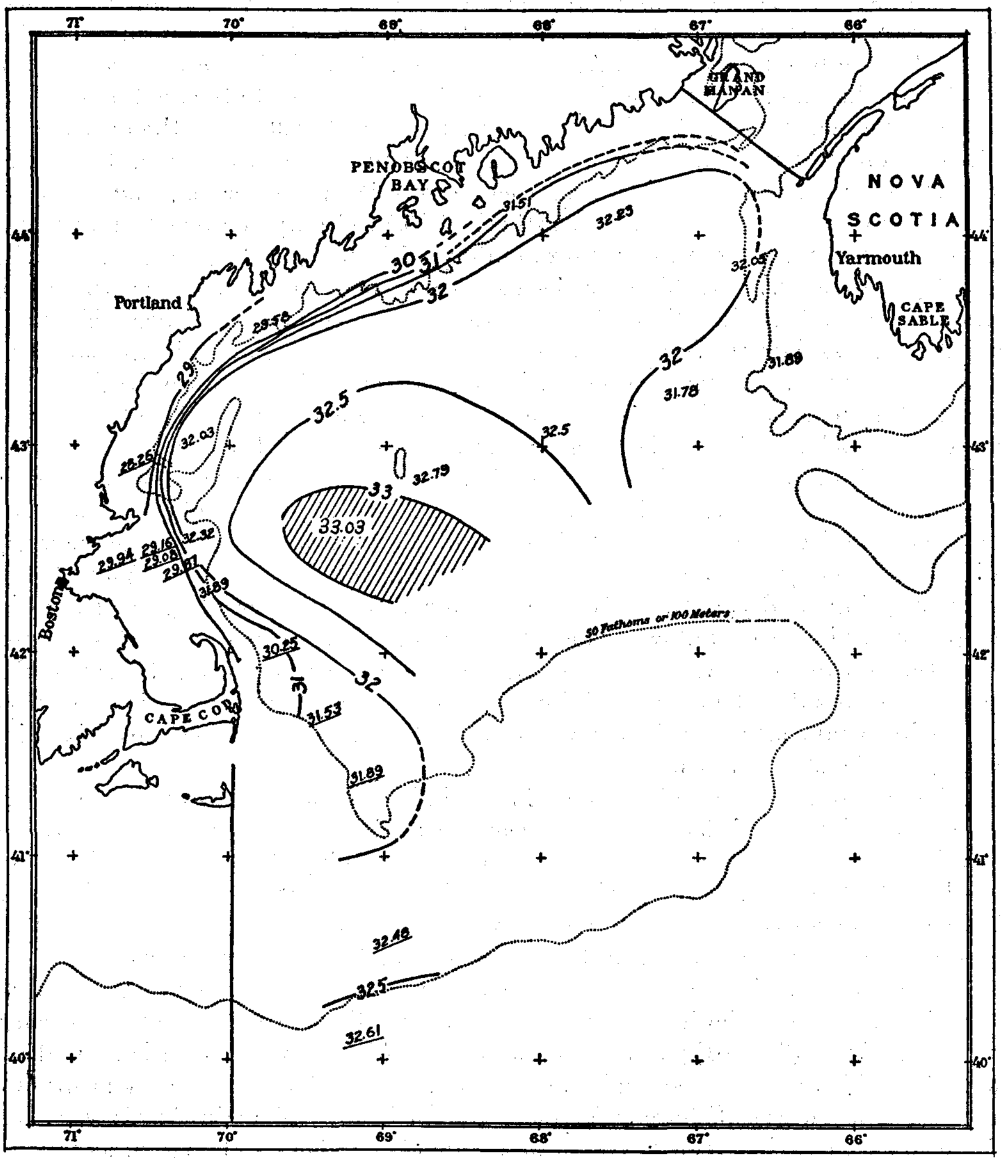

FIG. 120.—Salinity at the surface, May 4 to 14, 1915, combined with May 4 to 17, 1920

The most instructive feature of the May chart in the eastern side of the gulf is the similar expansion of surface water less saline than 32 per mille westward over the basin from the offing of Cape Sable, which owes its low salinity to the Nova Scotian drift from the eastward.

The critical isohaline (32 per mille) bounding this tongue had been carried about as far west into the gulf as this at least a week earlier in the spring of 1919, with actual values almost precisely the same.[88] Consequently, the picture presented on the surface chart for May (fig. 120) may be taken as typical of the season when the flow into the gulf past Cape Sable is at its maximum, irrespective of the precise date when this falls.

The lack of data on the salinity of the southeastern part of the Gulf of Maine for May is a serious gap, for without such it is impossible to tell how far the freshening effect of the Nova Scotian water extends toward Georges Bank, or over the latter, when it is at its maximum. However, it is certain that water of low salinity from this eastern source did not reach the southwestern part of the bank at any time prior to the 17th of May in 1920, whatever may have happened later that spring, because no appreciable alteration took place in the salinity of the surface, which was about the same there on that date (station 20129) as it had been on February 22 (station 20045).

We also await observations on the salinity of the shoal water along the west coast of Nova Scotia for May, to show how low it is reduced there by vernal freshening from local sources. It is not likely, however, that the eastern margin of the open Gulf of Maine ever falls below 30 per mille in salinity, unless right at the mouth of some stream, because no large rivers open along this part of the coast, because the outflow from the Bay of Fundy is directed westward (p. 916), and because there is no reason to suppose that the Nova Scotian current ever brings water less saline than about 30.8 to 31.5 per mille past Cape Sable.[89]

It is a question of moment in the natural economy of the gulf whether and to what extent the water of the Nova Scotian current turns northward after it has passed Cape Sable. This the reader will find discussed in another chapter (p. 680). I need remark here only that the surface salinities for May, 1915, and especially the course of the isohaline for 32 per mille (fig. 120), mark a westward drift toward the center of the gulf; but considerably lower salinities off the mouth of the Bay of Fundy in May, 1915, than in April, 1920, suggests some movement of water in that direction also, from the cape, as characteristic of this season.

The vernal freshening of the coastal belt of the gulf by land water, and of the eastern side by the Nova Scotian current, are annual events, though differing from year to year in their time schedule as well as in the magnitude of the alterations they cause. A considerable divergence from year to year has been recorded in May in the west-central part of the gulf, which neither of these sources of low salinity appreciably affects up to that season. If the early May state of this part of the gulf in 1915 (fig. 120) be the regular seasonal sequence to the April state, as represented by 1920 (fig. 101), a considerable salting of the superficial water layer is to be

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[88] Surface salinity 31.98 per mille at Ice Patrol station 21; 31.71 per mille at Ice Patrol station 22 on German Bank.

[89] Neither the Ice Patrol nor the Canadian Fisheries Expedition have reported salinities lower than 30.8 per mille along the outer coast of Nova Scotia in April or May.

expected there, raising the surface value from 32.5 to 33 per mille over the western arm of the basin from the one month to the next. An increase of this sort in the surface salinity, taking place at a season when the waters to the west and to the east freshened, would of itself suggest local upwelling. This explanation is corroborated, also, by the fact that the upper 120 to 130 meters proved nearly as homogeneous there vertically, in salinity, on that occasion as in either March or April, and about 0.6 per mille more saline in absolute value (fig. 112), instead of showing the considerable vertical range of salinity that might otherwise be expected to develop in this region by May.

West–east profiles of the gulf also give unmistakable evidence that some such circulatory movement did take place in 1919 between the end of April and the end of May (fig. 121), by which date a strong pulse in the inflowing bottom current had raised the upper boundary of water, more saline than 32.5 per mille, to within 20 meters of the surface in this side of the basin. Some upwelling is therefore to be expected in the western side of the basin from April through May, correlated with the speeding up of the anticlockwise circulation that follows the freshets from the rivers tributary to the gulf (p. 916). The actual alteration which this effects in the salinity of the surface stratum, however, may not be as wide in any given year as the difference between the April records for 1920 and those for May, 1915, might suggest, because it is possible that these two years illustrate two extremes—the one lower in salinity than is usual, the other higher.

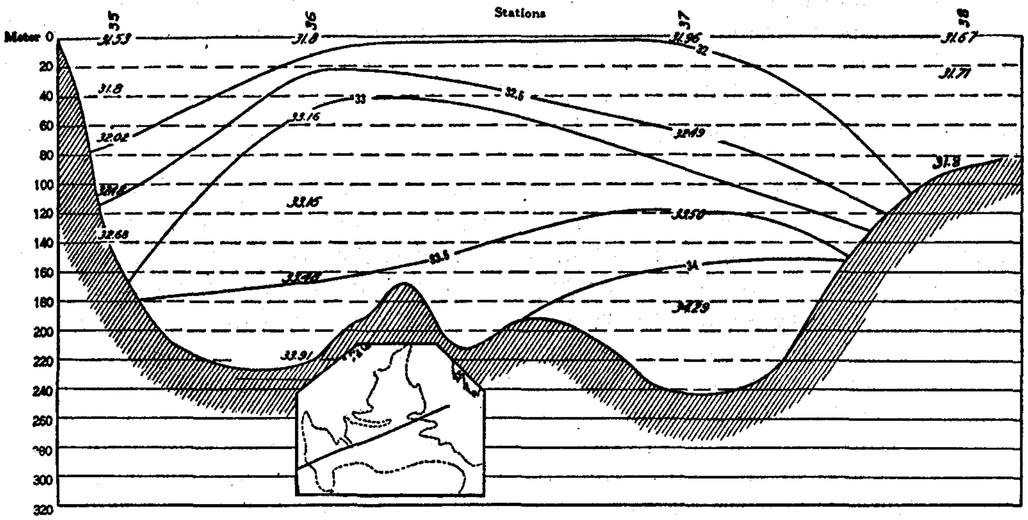

FIG. 121.—Salinity profile running eastward from the offing of Cape Cod toward Cape Sable, May 29 to 30, 1919 (ice patrol stations 35 to 38)

BELOW THE SURFACE

The fact that May sees the culmination of vernal freshening from the land, and also the maximum expansion of the Nova Scotian current past Cape Sable, lends interest to the subsurface salinities for the month.

Perhaps our most instructive illustration of how strictly the decrease in the salinity of the coastal belt is confined to the superficial stratum of water up to this season is afforded by the station data for 1920 at the mouth of Massachusetts Bay (station 20120) for May 4, when the upper 15 meters was near its minimum salinity for the year and homogeneous (29.1 to 29.2 per mille), but with the salinity increasing by 2 per mille in the next 15 meters of depth to 31.13 per mille at 30 meters. A vertical distribution of this type, coupled with the fact that the deeper water there was less saline on that date than it had been two weeks previous (station 20092), is evidence that when the tongue of water of low salinity described above (p. 741) first spread southward past Cape Ann, vertical mixing was active enough for it to dilute the whole column of water at the mouth of the bay. The latter, however, was followed in turn by an increase in the salinity of the whole column during the next 12 days, resulting primarily from a movement of more saline water inward over the bottom (fig. 122; stations 20120 and 20124).

Events seem to have followed a similar course in the Isles of Shoals region in 1913, when Mr. Welsh recorded a progressive increase in the mean salinity of the whole column of water, in depths ranging from 36 to 48 meters, from about 31.1 per mille on May 10 to 13, 31.5 per mille on the 13th, and 32.7 per mille on the 16th, resulting in the recovery of the bottom salinity (32.2 to 32.6 per mille) almost to the April value (32.5 to 32.8 per mille). Evidently the absorption of freshet water from the rivers into the general circulation was accompanied by some indraft of water of high salinity from offshore in this region; otherwise the mean salinity of the column of water would not have increased as it did.

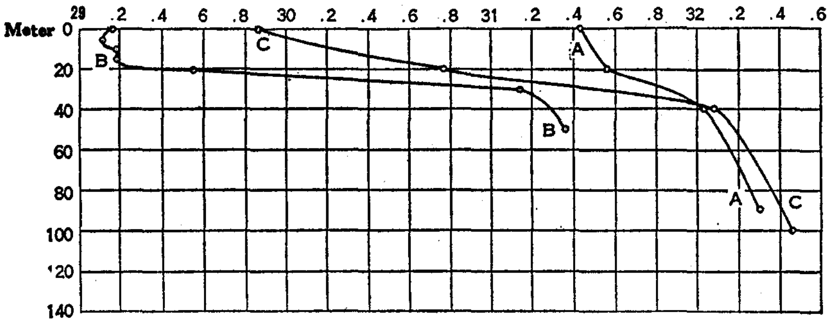

FIG. 122.—Vertical distribution of salinity at the mouth of Massachusetts Bay. A, April 20, 1920 (station 20119); B, May 4, 1920 (station 20120); C, May 16, 1920 (station 20124)

On the other hand, the salinity of the bottom water of Massachusetts Bay changed very little from April to May in 1925 [90] at depths greater than 40 meters, except for a slight decrease near Cape Ann, reflecting the surface drift from the north (p. 741). It is certain, therefore, that bottom water does not enter the bay every May in as great volume as it did in 1913 and 1920.

In the coastal sector between Cape Cod and Penobscot Bay the vertical range of salinity is wider in May than at any other time of year—widest of all off the river mouths and along the track followed by the discharges from the latter. Off the mouth of the Kennebec, for example, the surface had freshened to 29.6 per mille by May 13, 1915, a value about 3 per mille below that of the 50-meter level (about

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[90] *Fish Hawk* cruises 12 and 13.

32.4 per mille, station 10277). It is probable, also, that this generalization applies equally to the eastern coast of Maine, though our data are less satisfactory for this sector. Mavor's (1923) records for the springs of 1917 and 1918 also prove it equally applicable to the central part of the Bay of Fundy, where for a brief period in May and early June river water (chiefly from the St. John) causes a vertical range of salinity as wide as ever obtains anywhere in the open waters of the gulf.

In the eastern side of the gulf, however, which receives land water in only relatively small amount, the whole column continues so thoroughly mixed by the tidal currents throughout the spring that our standard station on German Bank (fig. 109) has shown no more difference between the surface and the bottom in May (station 10271 and Ice Patrol stations 22 and 38) than in April, on the one hand, or in June or August, on the other, though the actual values were considerably lower for May of the years 1915 and 1919 (31.7 to 32 per mille) than for any other month of record. This also applies to the vicinity of Lurcher Shoal, a few miles farther north (fig. 108), where the graph for May nearly parallels those for March, April, and September, though lower in salinity.[91]

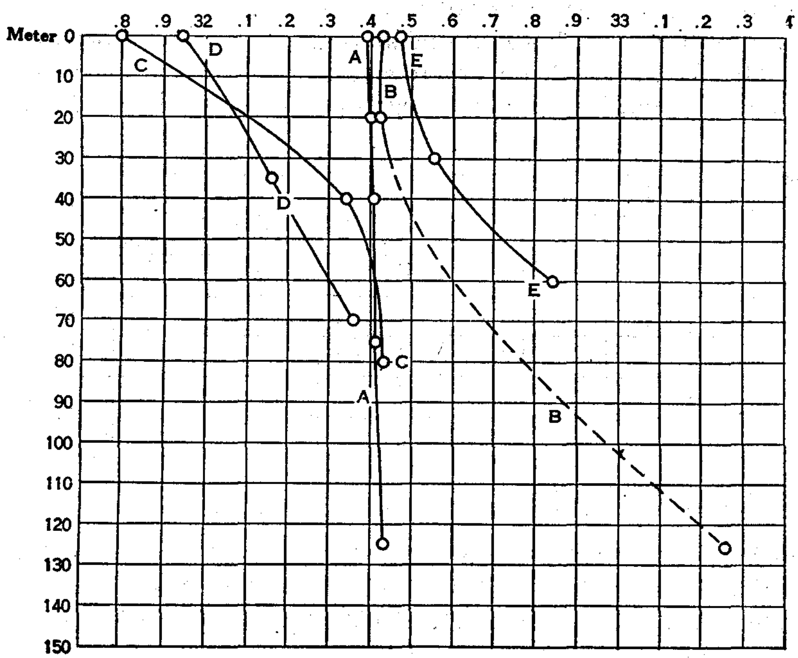

FIG. 123.—Vertical distribution of salinity off Penobscot Bay. A, March 4, 1920 (station 20057); B, April 10, 1920 (station 20097); C, May 12, 1915 (station 10276); D, June 14, 1915 (station 10287); E, October 9, 1915 (station 10329)

The directions in which the discharges from the large rivers spread out over the surface are betrayed by the vertical distribution of salinity as well as by the actual values as represented in horizontal projection. Thus, the fact that salinity altered very little in the trough off the Isles of Shoals from March to April, 1920 (stations 20061 and 20093), with the values for May 14, 1915 (station 10278), differing by less than 0.5 per mille from April, 1920, locates the line of transition (from the region of

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[91] Thirty-two per mille at the surface to 32.3 per mille on bottom in 90 meters, May 10, 1915, station 10272.

highly variable to that of more nearly constant salinity) close to the Isles of Shoals. The zone within which river discharge rapidly increases the vertical range of salinity in spring is no wider than this off Penobscot Bay, for the *Grampus* found the bottom (32.43 per mille) only about 0.6 per mille more saline than the surface (31.8 per mille) in 80 meters 3 miles off Matinicus Rock on May 12, 1915 (station 10276), though the whole column was 0.2 to 0.6 per mille less saline then than it was on the 9th of the following October (station 10329) or on January 1, 1921 (station 10496).

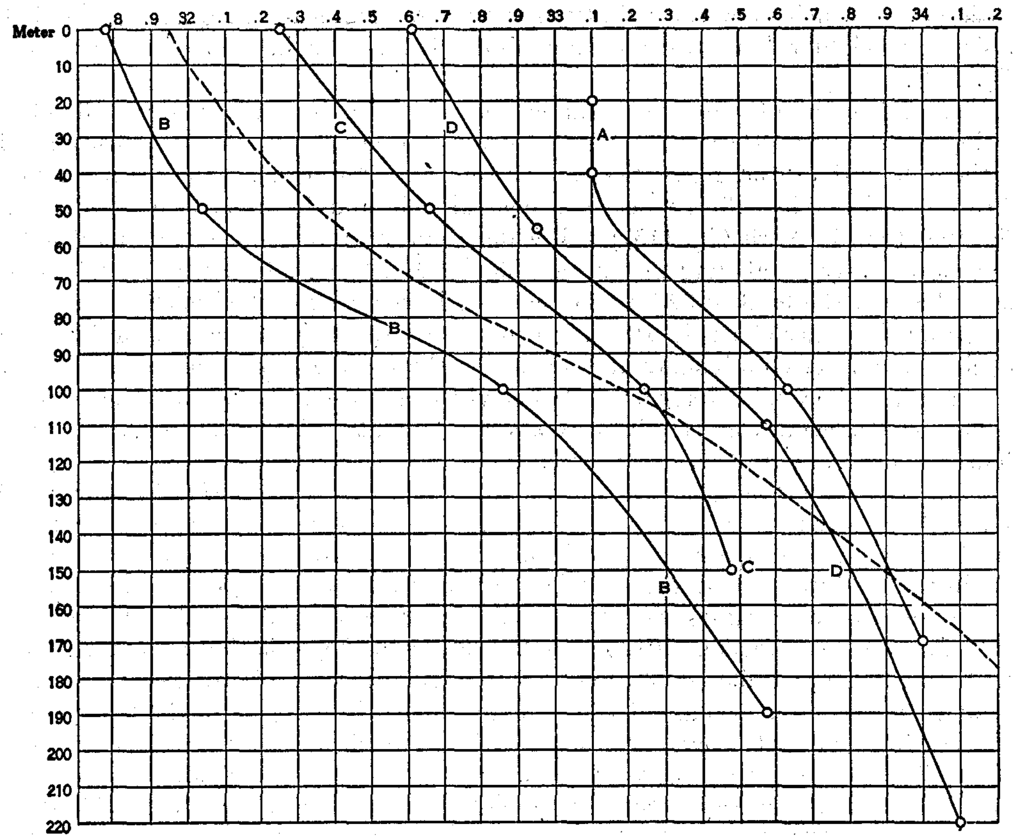

FIG. 124.—Vertical distribution of salinity in the eastern side of the basin of the Gulf of Maine on March 23, 1920 (A, station 20086); May 6, 1915 (B, station 10270); May 29, 1919 (broken curve, ice patrol station 37); June 19, 1915 (C, station 10289); and August 12, 1913 (D, station 10093)

The freshening effect of the Nova Scotian current affects the vertical distribution of salinity of the region influenced by it in precisely the same way as drainage from the land, by producing a wide range between the surface and the deep strata. The notable difference between graphs in the eastern side of the basin for March, 1920, and for May, 1915 and 1919, illustrate this (fig. 124) by a considerable freshening of the whole stratum of water shoaler than 100 meters.[92]

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[92] The actual data suggest a decrease of about 1 per mille at the surface and 0.7 per mille at 75 meters as normal for the period during which the drift from the east is gaining head; but annual fluctuations of unknown amplitude complicate the picture.

If the contrast between the salinities for the early spring of 1920 and for May, 1915, represents the succession normal for this time of year, a very considerable freshening also takes place at greater depths in the eastern side of the basin from March and April to May, the graphs (figs. 114 and 124) suggesting an average decrease of about 0.6 to 0.8 per mille at 100 meters and deeper. Such a reduction of the salinity back to about the March values naturally would follow any slackening of the inflowing bottom current, but would be less and less apparent the farther from its source of supply. A regional relationship of this sort does, in fact, result from our station data, which show the salinity of the bottom water of the western side of the basin only slightly lower in May and June, 1915, than in March or April, 1920 (fig. 112).

The upwelling of water more saline than 33 per mille in the western side of the basin, which follows or accompanies the incorporation of river water into the one side of the gulf and of the Nova Scotian current into the other, causes a much more abrupt transition in salinity between coastal belt and basin at 40 meters in May (fig. 125) than in April (fig. 115); still wider than in March, and a regional distribution more nearly paralleling the surface (fig. 120). The gradation from 31.7 to 31.9 per mille next the land to 32.8 to 33 per mille in the west-central parts of the basin, shown on this May chart, is probably typical for the month, though no doubt the precise spread between inshore and offshore values varies somewhat from year to year and would probably have proved somewhat narrower in 1925, when the 40-meter values for Massachusetts Bay in May averaged slightly higher (32 to 32.6 per mille) than was the case in 1915 or in 1920.

Up to May the decrease in salinity attributable to vernal freshening is confined to even a narrower coastal belt at 40 meters than at the surface, hardly any change being indicated more than 10 miles out from that contour line in the western side of the gulf[93] or farther south than the offing of Cape Cod, where the 40-meter values were somewhat higher on May 16 to 17, 1920 (32.3 to 32.5 per mille at stations 20125 and 20126), than they had been a month earlier (32.1 to 32.2 per mille at stations 20116 and 20117 on April 18). The salinity at this depth was also about the same in the southwest part of the basin and on Georges Bank in that May (32.5 per mille) as it had been at the end of February. In spite of this apparent agreement, however, the water less saline than 33 per mille must actually have increased considerably in volume in the offing of Cape Cod during the interval to account for its expansion out from the bank to the seaward slope of the latter, where salinity decreased by about 1 per mille at 40 meters between February 22 (station 20045, about 33.8 per mille) and May 17 (station 20129, about 32.9 per mille).

It is probable that the salinity of the 40-meter level falls below 32 per mille every May over a considerable area out from the Nova Scotian shore of the gulf, where the Nova Scotian current then holds sway; and if 1915 was a typical spring in these waters (which I see no reason to doubt) the drift of this water of low salinity from its more eastern source is directed more definitely westward toward the center of the gulf at this depth than it is at the surface, with less evidence of any dispersion northward toward the Bay of Fundy (p. 745). Reduced to terms of distance, the seasonal

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[93] This follows an extremely irregular course.

relationship just outlined points to a translation of the isohaline for 32 per mille about 100 miles westward from the location occupied by it before the current begins to flood past Cape Sable in appreciable volume.

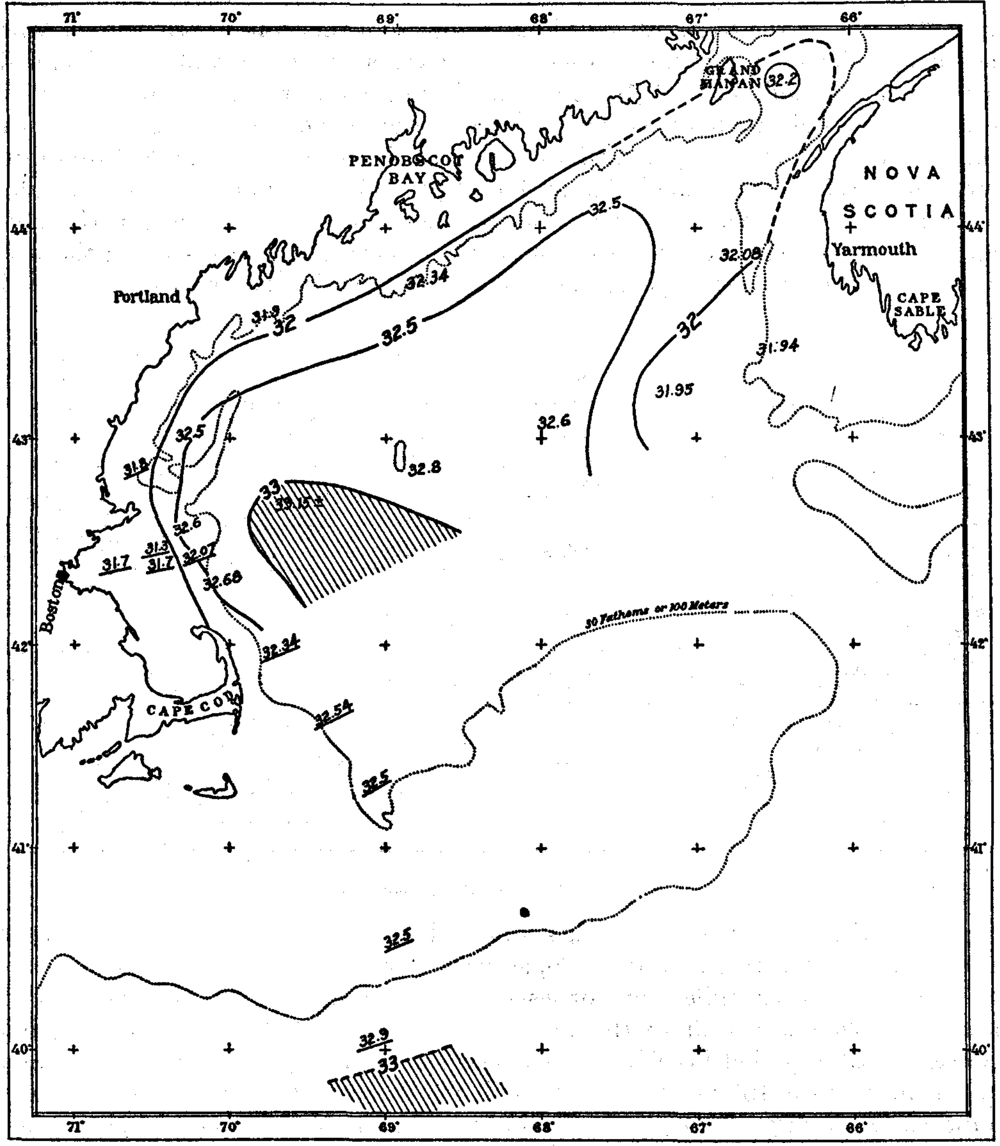

FIG. 125.—Salinity at a depth of 40 meters, May 4 to 14, 1915 (plain figures), combined with May 4 to 17, 1920 (underlined figures). The encircled figure in the Bay of Fundy is for May 4, 1917, from Mavor (1923). Dotted curves are assumed

Apparently this drift was still in operation at the date of our May cruise in 1915 (the 4th to the 10th). Had it not been, and had absorption of the water of low salinity from the east into the general circulation been well advanced, the transition from salinities lower than 32 per mille in the east to 32.6 to 32.8 per mille in the center of the gulf would hardly have been as abrupt as we actually found it (figs. 125 and 126). Therefore, the salinities prevailing at the time were not reminiscent of some preceding event (as is too often the case), but evidence of a present state of circulation.

The isohaline for 32 per mille reached the eastern side of the basin at the time (fig. 126); and as the *Grampus* sailed eastward from this station (10270) on May 6 she did actually stem a current flowing westward with considerable velocity, as described in a later chapter (p. 917). In fact, it is unusual for the distribution of salinity to accord as closely with direct navigational observation of a surface current as happened on this occasion. The profiles for 1919 also show this Nova Scotian drift (outlined in this case by the isohaline for 32 per mille) reaching the eastern side of the basin, but no farther, at the beginning of May and again at the end of the month (fig. 121), in each case wedge-shaped in longitudinal section and involving the whole upper 100 meters on the slope of German Bank, but thinning out to nothing at its western edge.

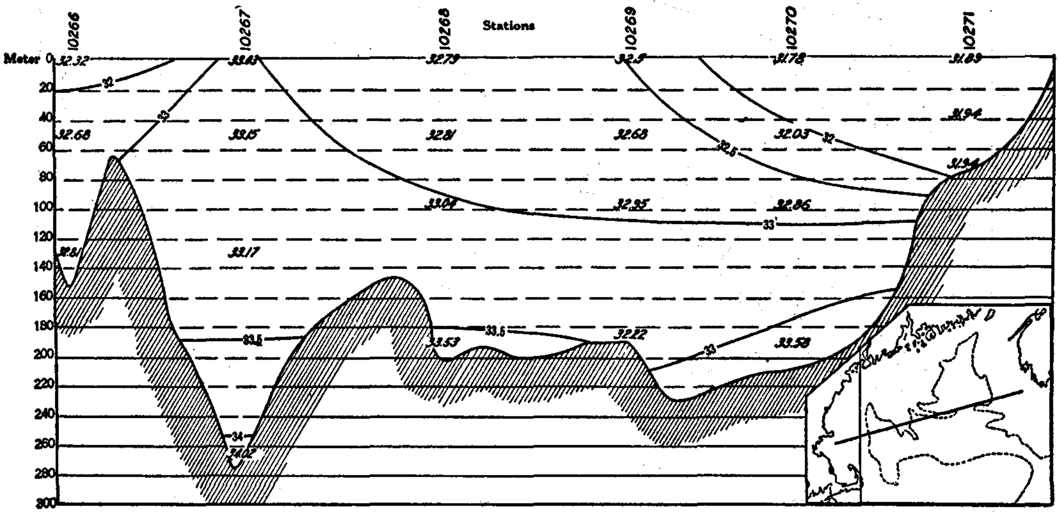

FIG. 126.—Salinity profile running eastward from the mouth of Massachusetts Bay to German Bank, May 4 to 7, 1915

If the May charts for 1915 (figs. 125 and 127) represent the normal seasonal succession to the April charts for 1920, as close correspondence in 1919 makes likely, an increase of 0.5 per mille (more or less) may be expected in the western side of the basin from the one month to the next at the 40-meter level, contrasting with the decrease in salinity that involves the whole coastwise zone, and an increase of about 0.2 per mille at the 100-meter level, though the precise magnitude of this change no doubt varies from year to year. This is reflected at the 40-meter level, just as at the surface, by a shift of the most saline center across the basin of the gulf from east to west (cf. fig. 115 with 125), as well as by the development of a mass of water of high salinity in the upper 100 meters in the offing of Massachusetts Bay, illustrated in profile (figs. 121 and 126).

This slight increase in salinity in the western side of the basin, coupled with the freshening of the eastern side for which the Nova Scotian current is responsible, tends to equalize the regional inequalities in the mid levels of the gulf (fig. 127) as the spring draws to a close. Thus, the extreme range of salinity in the gulf was little more than half as wide at 100 meters in May, whether of 1915 or of 1920 (about 0.7 per mille, fig. 127), than in April or in March of 1920 (respectively, 1.1 and 1.3 per mille, figs. 94 and 116). At 175 meters (chosen as representative of the deep water of the gulf because this particular contour best outlines the trough of its basin) the extreme range of salinity was only 0.5 per mille (32.94 to 33.46 per mille)

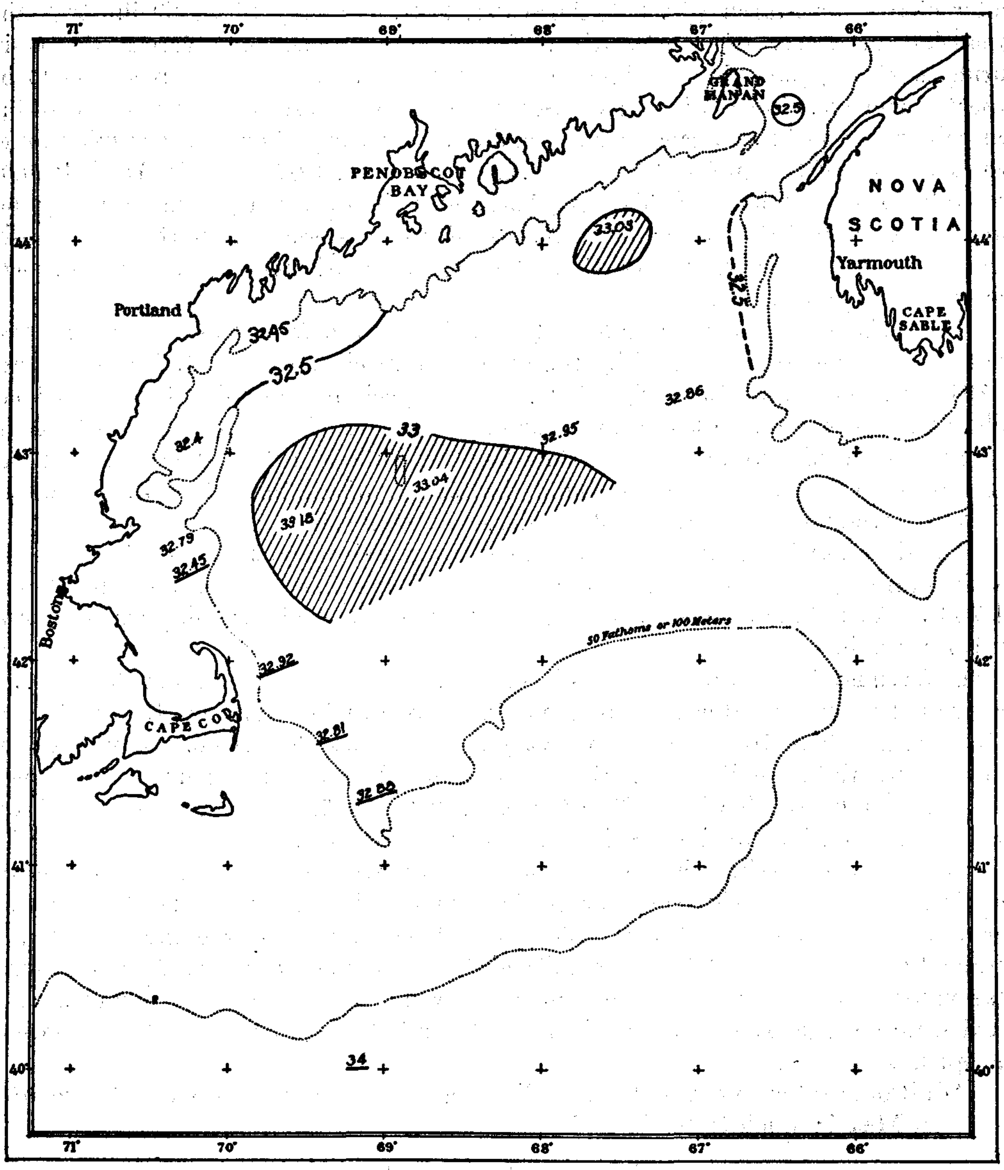

FIG. 127.—Salinity at a depth of 100 meters, May 4 to 14, 1915 (plain figures), combined with May 4 to 17, 1920 (underlined figures). The encircled figure in the Bay of Fundy is for May 4, 1917, from Mavor (1923)

for the northern side during the first half of May, 1915—i. e., less than half the regional variation recorded there for March and April of 1920 (32.91 to 34.1 per mille).

The locations of the isohalines for 33 per mille from month to month on the 100-meter charts for March (fig. 94), April (fig. 116), and May (fig. 127) illustrate the expansion of water of comparatively high salinity westward across the basin during a strong pulse in the inflowing bottom current, and the recession to be expected when the indraft is weak. Some change of this sort is consistent with the general progress of the vernal cycle. Salinity averaging about 0.6 per mille lower over the basin of the gulf at 175 to 200 meters in May, 1915, than in April, 1920, is probably to be explained on this same basis; but the observations taken by the Ice Patrol cutter in 1919, when the salinity of the east-central part of the basin increased through May, proves that the indraft continues active right through the month in some years.

The differences that may be expected in this respect from one May to the next are more graphically illustrated by the west-east profiles of the gulf for that month of 1915 (fig. 126) and 1919 (fig. 121). Note especially the thick band of 34 per mille water on bottom in the latter year in the eastern side of the gulf, where the value was only slightly more saline than 33.5 per mille in 1915. The fact that this is the only month when we have found the salinity of the basin lowest, as a whole, in the eastern side, not in the western, deserves emphasis.

The decrease in salinity that took place from February, 1920, to May over the continental slope to the southwest of Georges Bank has already been mentioned (p. 750). At 100 meters the May value (station 20129, ±34 per mille) was the lower by 1.3 per mille.

Unfortunately no water samples have been collected in May along the 400-mile sector of the continental edge from the offing of Nantucket eastward to the offing of Sable Island, where 100-meter values varying from 33.4 to 34.8 per mille have been reported by the Canadian Fisheries Expedition (Bjerkan, 1919; *Acadia* stations 9 and 10) and by the Ice Patrol[94] in the years 1914, 1915, and 1922, evidence of considerable fluctuations in the physical state of the slope water.

With the low values just stated, and values even lower at the same relative location off the eastern slope of Georges Bank in March and April, 1920 (32.8 to 33.46 per mille at 100 meters, stations 20068 and 20109), off Shelburne, Nova Scotia, on March 19 of that year (33.78 per mille at 100 meters, station 20077), it is evident that water of 35 per mille is usually separated from the slope by lower salinities eastward from Georges Bank to the tail of the Grand Banks during the third month of the spring.

Additional information as to the salinity along the seaward slope of the Scotian Banks in May is much to be desired.

SALINITY IN JUNE

A tendency toward progressive equalization is recorded from May to June as the overflow of the Nova Scotian current past Cape Sable and the outpourings of river waters are gradually incorporated into the gulf.

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[94] Ice patrol station 29, May 17, 1914, 34.05 per mille at 200 meters; station 24, May 19, 1915, 33.66 per mille at about 100 meters; station 213, May 28, 1922, 34.79 per mille at 100 meters; see U. S. Coast Guard (1916) and Fries (1923).

In the year 1915 salinity was determined at 19 stations in June, sufficing to outline the regional and vertical distribution for the eastern side of the area and out across the shelf south of Cape Sable; while the *Fish Hawk* stations for 1925 extend the picture to Massachusetts Bay.

The most instructive feature of the surface chart for June, 1915 (fig. 128), is its demonstration that the drift of water of low salinity into the gulf from the east had slackened, if not entirely ceased, since mid May, the isohaline for 32 per mille having shifted 50 miles or so eastward from the location it occupied six weeks earlier (fig. 120), the salinity of this side of the basin having increased from 31.78 per mille to 32.25 per mille during the interval. While the Nova Scotian drift may have extended to the eastern parts of Georges Bank in May (p. 745), an abrupt transition along the eastern side of the Eastern Channel in June, from low values over Browns Bank (31.5 per mille) to higher ones farther west, shows that it had ceased to expand in this direction by that time.

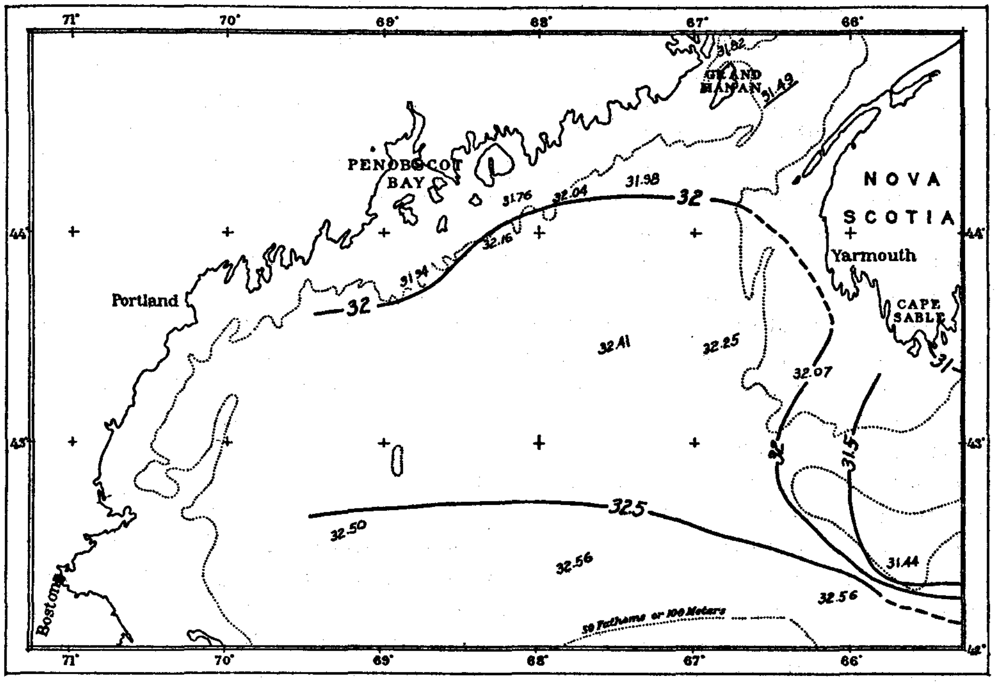

FIG. 128.—Surface salinity of the eastern and central parts of the Gulf of Maine, June, 1915

The incorporation of river water, which is responsible for vernal freshening of the coastal belt, was reflected in 1915 by an average increase of 0.2 to 0.5 per mille in surface salinity along the northern margin of the gulf from May (fig. 120) to June (fig. 128, values ranging from 31.8 to 32.2 per mille).

Within the Bay of Fundy, where the effects of the freshets from the St. John River are responsible for a very sudden freshening of the surface from April to May, as described above (p. 743), the recovery is correspondingly more rapid than in the open gulf, where the influence of any one river is spread over a wider area. In 1917, for example, the salinity of the surface water between Grand Manan and Nova

Scotia rose from 27.9 per mille on May 4, to 31.49 per mille on June 15 (Mavor, 1923, p. 375); and some such succession may be expected close in to the mouth of any one of the large rivers that drain into the gulf.

No observations were taken in the western side of the gulf in June, 1915; but the *Fish Hawk* stations for 1925 (figs. 129 and 130) show a similar increase of about 0.7 per mille in the surface salinity of Massachusetts Bay, from a mean of 31.57 per mille on May 20 to 22 to a mean of 32.28 per mille on June 16 to 17, with no evidence of the drift of water of low salinity into the bay from the north past Cape Ann, which the isohaline for 31.5 per mille made apparant three weeks earlier (fig. 119).

Contrasting with the general rise in surface salinity that takes place alongshore and over the eastern side of the basin from May to June, as just described, the charts for 1915 (figs. 120 and 128) show a corresponding freshening of the surface over the western side of the basin, resulting from the general dispersal of land water out to sea combined with a cessation of the upwelling that was taking place there in May (p. 746). In that particular year the actual decrease off Cape Ann was from 33 per mille on May 5 (station 10267) to 32.5 per mille on June 26 (station 10299)—evidence of the gradual tendency toward the equalization that follows the temporary freshening or salting of any part of the gulf.

I can say nothing of salinity over Georges Bank or for Nantucket Shoals in June; data there for that month are desiderata.

Although no notable alteration takes place in the vertical distribution of salinity from May to June, the following minor changes are worth attention:

The western branch of the basin, off Cape Ann (fig. 112), freshens notably from the one month to the next in the upper 40 to 50 meters, but salts at depths greater than 120 meters, resulting in a considerably wider range of salinity between surface and bottom, a change important because of the greater vertical stability it gives to the column of water as a whole.

It is doubtful, however, whether any seasonal alteration of this order extends to the southeastern part of the basin, because the salinity of the upper 50 to 60 meters was almost precisely the same there on June 25, 1915 (station 10298), as it was two months earlier in the season in 1920 (station 20112, April 12); and while the June station was slightly the salter of the pair at 100 meters, it was slightly the fresher from 150 meters downward to the bottom. In the eastern side of the basin, too, the vertical range of salinity decreases from May to June, instead of increasing, as the Nova Scotian current slackens. The whole column of water over German Bank was likewise (and for the same reason) about 0.2 per mille more saline on June 19 (station 10290, about 32.1 per mille) than it had been on May 7 (station 10271), though as nearly homogeneous vertically, a condition maintained here the year round by active tidal stirrings.

In the Bay of Fundy, between Grand Manan and Nova Scotia, Mavor (1923, p. 375) found much less spread between surface and bottom on June 15, 1917, than on May 4, consequent on the considerable salting of the upper stratum just described (p. 755); and the contrast between the moderately wide vertical range of salinity there, as well as at our own station at the mouth of the bay on June 10, 1915 (station 10282), and the vertical homogeneity of the water of the Grand Manan

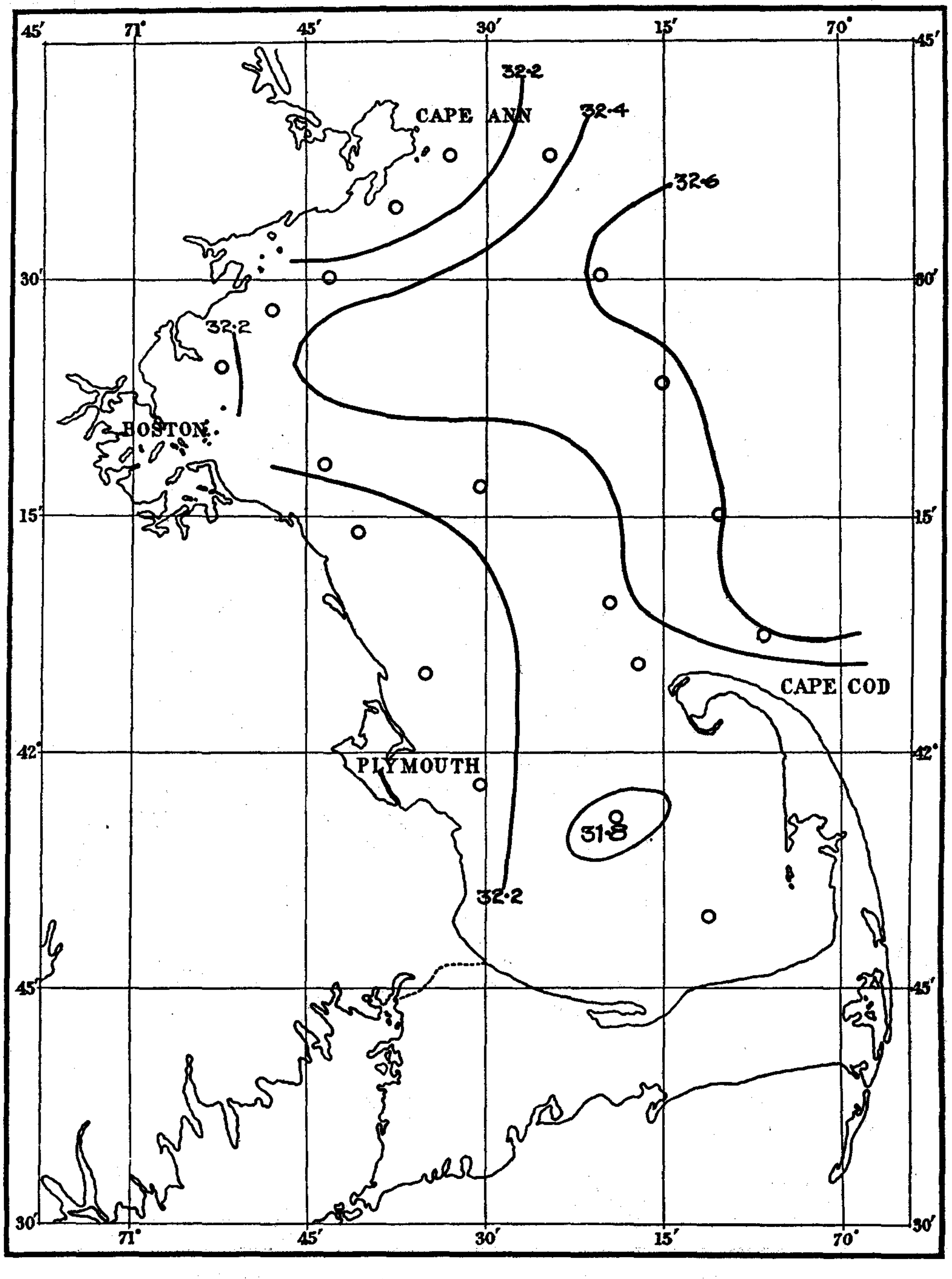

FIG. 129.—Salinity of Massachusetts Bay at the surface, June 16 to 17, 1925

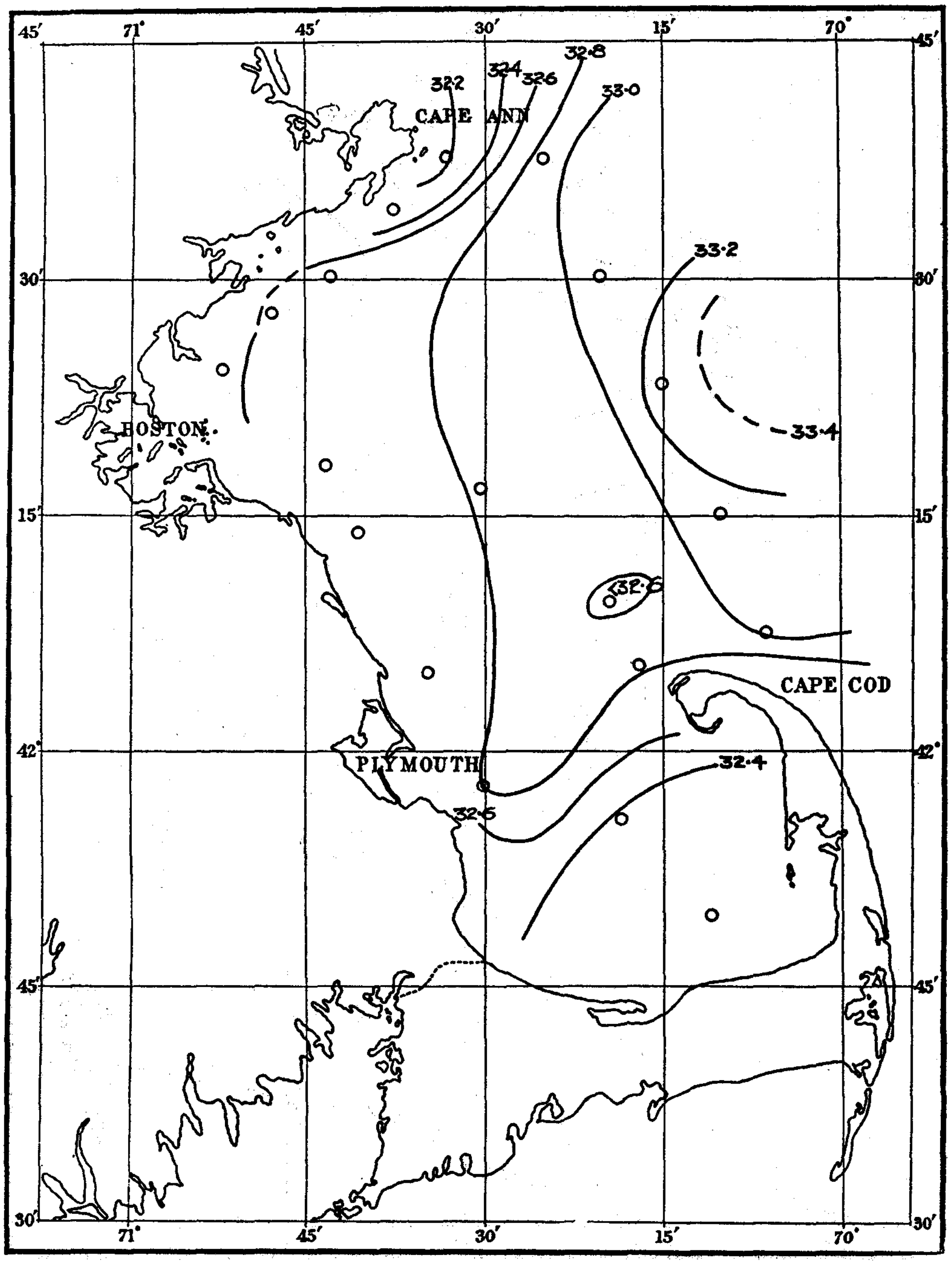

Fig. 130.—Salinity of Massachusetts Bay at 20 meters, June 16 to 17, 1925

Channel on the 4th (station 10281, 31.8 per mille from surface to bottom), is an interesting illustration of the local differences to be expected at neighboring stations in these tide-swept waters.

Near Mount Desert, too, observations taken at three stations on June 11 to 14, 1915 (stations 10284, 10285, and 10286), show much less difference between surface and bottom than on May 10 and 11 (stations 10274 and 10275), the surface having salted by about 0.5 per mille in the interval, but the bottom by not more than 0.2 per mille. Off the mouth of Penobscot Bay, however, near the 100-meter contour, no appreciable change took place in the salinity at any depth from May 12, 1915 (station 10276), to June 14 (station 10287).

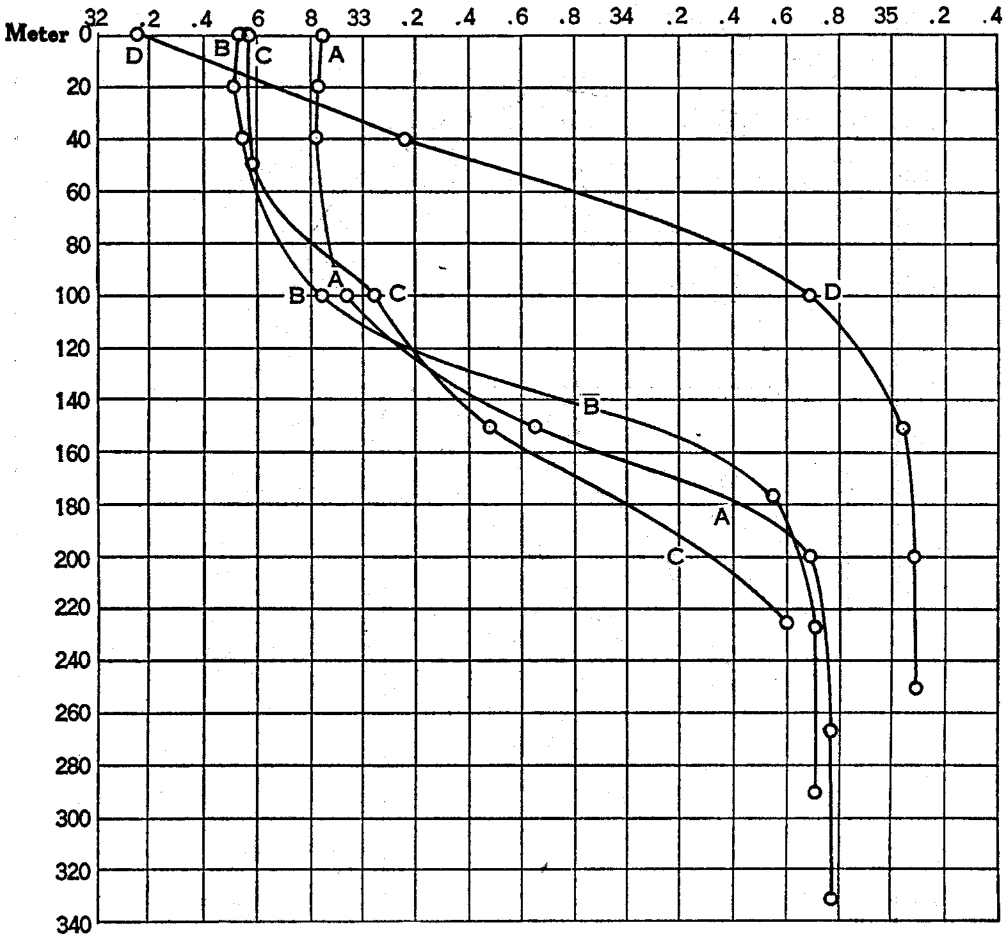

FIG. 131.—Vertical distribution of salinity in the southeastern part of the basin of the gulf. A, March, 1920 (station 20064); B, April, 1920 (station 20112); C, June, 1915 (station 10298); D, July, 1914 (station 10225)

In Massachusetts Bay, which receives very little river water from its own coast line, the *Fish Hawk* cruises of 1925 showed an increase in salinity, surface to bottom, between the 20th of May (cruise 13) and the middle of June, averaging about 0.7 per mille for all the stations and levels combined, with a maximum change of 1.3 per

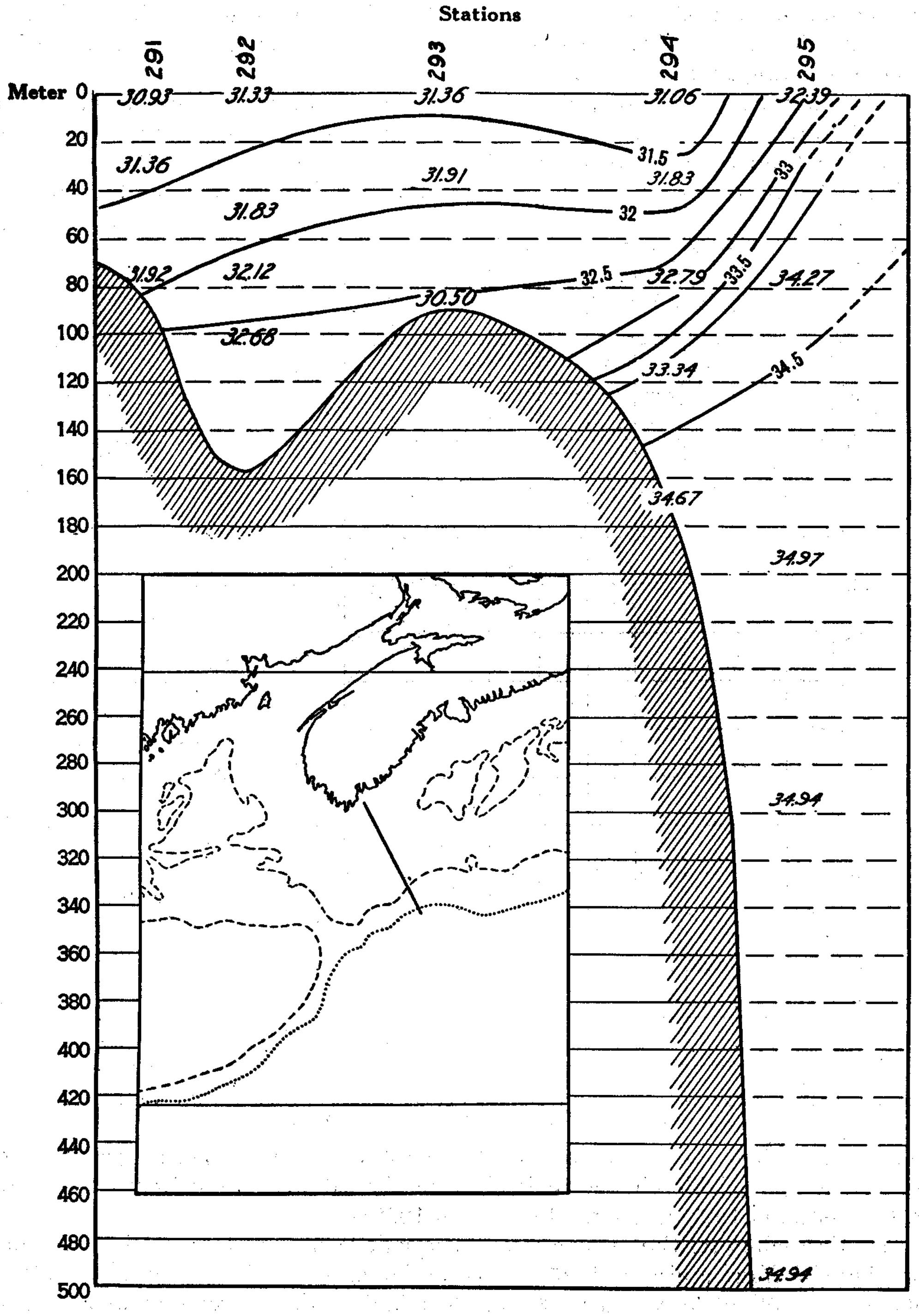

FIG. 132.—Salinity profile running southeastward from the offing of Shelburne, Nova Scotia, to the continental slope, June 23 to 24, 1915 (stations 10291 to 10295) Bottom value at station 10293 should read 32.50

mille, a minimum of 0.1 per mille. This salting was greatest (0.7 to 0.8 per mille for the whole column) across the mouth of the bay (stations 30 to 34) and inward over its deep central part (stations 18A and 3), consistent with the fact that the source for any change of this order must lie in the still higher salinities of the deep water of the basin in the offing. In spite of small local variations, however, which are always to be expected from station to station near shore, depending partly on the stage of the tide when the observations are taken, the average difference in salinity between the surface of the bay and the 40-meter level was almost precisely the same on the June cruise (0.7 per mille) as it had been three weeks earlier in the season.

The June stations (fig. 132) on the continental shelf off Shelburne, Nova Scotia (10291 to 10295), though outside the geographic limits of the gulf, strictly construed, are interesting in this connection as affording a cross section of the westward extremity of the Nova Scotian current at the time. Here the vertical range of salinity was wider than anywhere in the Gulf of Maine in that month, with values comparatively uniform, depth for depth, over the shelf but considerably higher outside the 100-meter contour (station 10295).

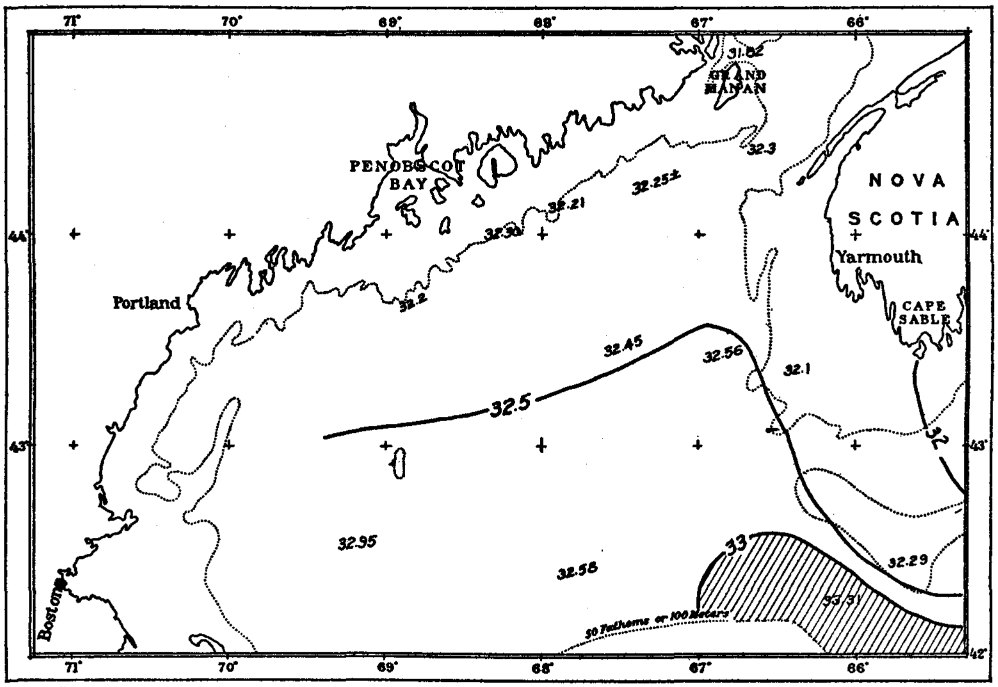

FIG. 133.—Salinity at a depth of 40 meters, last half of June, 1915

Horizontal projections give a more graphic spacial picture of the seasonal alterations just stated. At the 40-meter level the relationship between May (fig. 125) and June (fig. 133) is much the same as at the surface (p. 756)—the eastern side of the gulf salter than in May, the western and northern sides of the basin less so, as reflected by a translation of the isohaline for 32.5 per mille well out into the basin from the position close to the coast of Maine, which it had previously occupied.

Although no considerable shift of this particular isohaline is indicated off Massachusetts Bay by the data for 1925 (*Fish Hawk* cruise 14), the 40-meter level was more nearly uniform in salinity there that June (32.6 to 33.4 per mille) than it had been the month before.

At greater depths in the gulf (as illustrated by the 100-meter level), which are but slightly affected by the spring freshets from the rivers or by the Nova Scotian current, the mean salinity increased by about 0.2 per mille in the eastern side of the basin from May (fig. 127) to June (fig. 134) in 1915, but continued almost constant in the western side. Mavor (1923) has also recorded an increase in the salinity of the deep water of the Bay of Fundy during this same period, from 32.5 per mille at 100 meters on May 4, 1917, to 32.7 per mille on June 15. A change of the same sort was registered in the bottom of the open basin, as illustrated by the following tables:

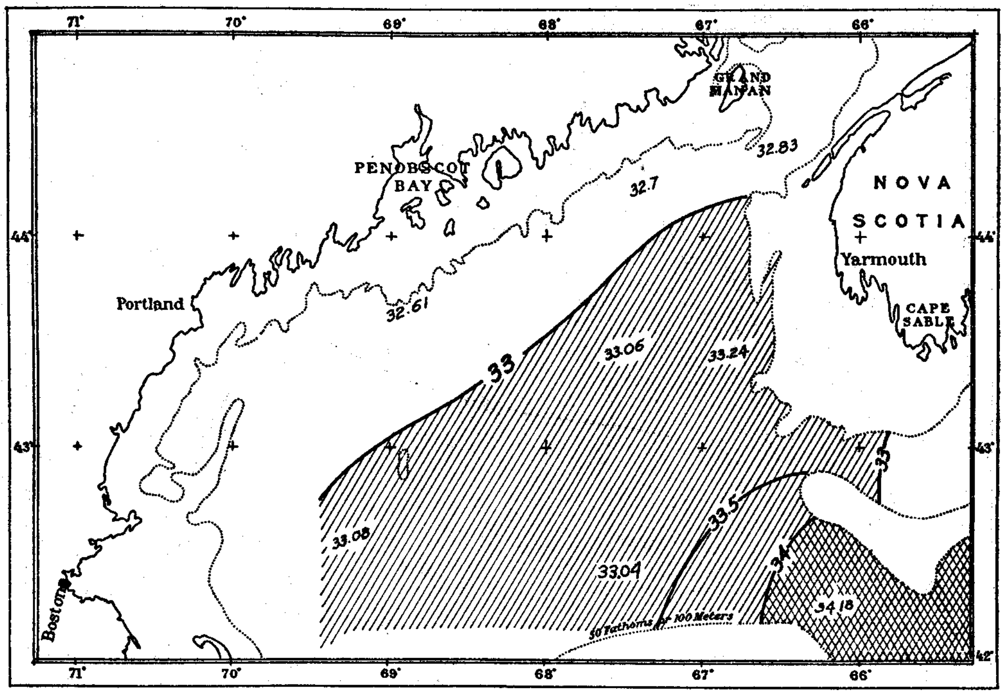

FIG. 134.—Salinity at a depth of 100 meters, last half of June, 1915

Salinities (per mille) at 175 meters

Date	Northeastern corner	Easternside	Southeastern part	Eastern Channel	Western basin	Center
March, 1920	33.78	34.04	34.20	34.53	33.82	33.08
April, 1920	34.02	34.30	34.56	34.60	33.84	34.18
May, 1915	33.40	33.46			33.37	33.45
June, 1915	33.60	33.64	34.00	34.80	33.55	33.50

Salinity on the bottom of the trough, June, 1915.

Locality	Depth	Salinity	Locality	Depth	Salinity
	Meters	*Per mille*		*Meters*	*Per mille*
Fundy Deep, station 10282	180	33.06	Eastern Channel, station 10297	275	34.92
Northeastern corner, station 10283	180	33.66	Southeastern corner, station 10298	225	34.60
Eastern basin, station 10288	220	33.95	Western basin, station 10299	210	33.82

The fact that the whole trough of the gulf was nearly as saline in the last half of June, 1915, as we found it in April, 1920 (p. 737), suggests a recovery of the indraft of slope water during the last half of May and first days of summer; but if such a recovery actually took place in 1915 it seems soon to have slackened again, judging from the rather abrupt transition from higher salinities in the Eastern Channe to lower ones just within the basin of the gulf recorded during the third week of that June (see the preceding tables).

The expansions and contractions of 34 per mille water over the floor of the gulf, and the depth at which its upper limit lies below the surface of the water at any given time, more clearly reflect the recent activity of the indraft through the Eastern Channel than does the distribution of salinity at any given level in the water. In April, 1920, water as salt as this flooded the bottom of both arms of the basin, rising up to within about 140 to 175 meters of the surface along the eastern slope of the gulf (fig. 118). In June, 1915, however, 34 per mille water was confined to the southeastern corner of the basin (station 10298) close to the entrance of the Eastern Channel.

SALINITY IN JULY AND AUGUST

SURFACE

If the readings taken in the western side of the gulf in July of 1912, 1913, and 1916 represent the normal succession to the June state of 1915 and 1925 (just described), the surface of this part of the area suffers a second freshening from 32 to 32.5 per mille in June to 31.4 to 31.9 per mille in July, but with little or no change from the one month to the next along the coast of Maine (31.5 to 31.8 per mille in July as well as in June). If this represents the regular seasonal progression it probably reflects the anticlockwise surface drift, carrying the discharges of the eastern rivers around the gulf to the Massachusetts Bay region a month or more after their freshening effect has been entirely obscured off the coast of Maine by tidal stirrings. This explanation is supported by the fact that the July values for the surface of the bay were lowest in 1916 (30.5 to 31.2 per mille), when a very tardy spring, with unusually heavy snowfall, would make a seasonal sucession of this sort the most likely. The surface water of the western part of the basin of the gulf, in the offing of Cape Ann, has proved less saline in every August of record (1913, 1914, and 1915) than it is in May (p. 741) or June (p. 756), in the following seasonal sequence and for the same reason:

Surface salinity, western basin

Date	Station	Salinity	Date	Station	Salinity
		Per mille			*Per mille*
May 4, 1915	10267	33.03	Aug. 9, 1913	10088	32.21
June 26, 1915	10299	32.50	Aug. 22, 1914	10254	31.55
July 15, 1912	10007	31.62	Aug. 31, 1915	10307	32.47

The exact date when this side of the basin is least saline varies from year to year, likewise the minimum value to which the salinity of the surface falls there, our experience up to date suggesting 31.5 to 32.2 per mille as usual at its lowest. In the same way the freshening recorded by Mavor (1923) in the Bay of Fundy early in the summer of 1917 may reflect the transference of the water of low salinity from the Nova Scotian current northward along the eastern side of the gulf, following the route of many of our drift bottles (p. 895).

Apart from this question, the most interesting aspect of the late summer data for the inner parts of the gulf is the comparative uniformity prevailing at the surface all along the coastal belt from Massachusetts Bay to Grand Manan in 1912 and 1915 (31 to 31.9 per mille). It is probable that the isohaline for 32 per mille usually crosses outside the mouth of the Bay of Fundy in July, because Vachon (1918) and Mavor (1923) record surface salinities ranging from 30.36 to 31.48 per mille at various localities in Passamaquoddy Bay and off Grand Manan for that month in 1916; 30.61 per mille at *Prince* station 3, east of Grand Manan, on July 4, 1917; rising to 31.22 per mille there on July 31.[96]

A considerable body of data has been gathered in the open gulf for the last half of July and for the month of August in the years 1912, 1913, 1914, 1915, and 1922, which, with the determinations for the Bay of Fundy for the summers of 1914, 1917, and 1919 (Craigie, 1916b; Vachon, 1918; and Mavor, 1923) afford a picture of the normal midsummer state of the surface of the gulf, with some indication of the annual fluctuations to which it is subject.

For salinity, as for temperature, the period, July to August, is the most nearly static part of the year in the open gulf, a statement supported by the following surface readings at pairs of stations at proximate localities but taken several weeks apart.

Locality	Date	Station	Salinity
			Per mille
Near Gloucester	July 12, 1912	10005	31.67
Do	Aug. 31, 1912	10046	31.67
Off northern extremity of Cape Cod	July 8, 1913	10057	31.90
Do	Aug. 9, 1913	10087	32.09
Southwest part of basin	July 19, 1914	10214	31.80
Do	Aug. 23, 1914	10256	31.80
Near Cape Sable	July 25, 1914	10230	31.47
Do	Aug. 11, 1914	10243	31.67
Off Grand Manan (Prince station 3)	[a] July 4, 1917		30.61
Do	[a] July 31, 1917		31.22
Near Mount Desert Island	July 19, 1915	10302	31.83
Do	Aug. 18, 1915	10305	31.94
Off Penobscot Bay	Aug. 2, 1912	10021	32.43
Do	Aug. 21, 1912	10038	32.32
Near Isles of Shoals	July 22, 1912	10012b	31.92
Do	Aug. 24, 1912	10041	32.07
Eastern side of basin	June 19, 1915	10288	32.41
Do	Sept. 1, 1915	10309	32.47
Western side of basin	June 26, 1915	10299	32.50
Do	Aug. 31, 1915	10307	32.47
Near Nantucket Shoals lightship	July 9, 1913	10060	32.63
Do	[b] Aug. 8, 1913		32.77

[a] Mavor, 1923. [b] Captain McFarland.

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[96] Surface densities, determined from hydrometer readings in the Bay of Fundy region, also indicate salinities ranging from 30.7 per mille to 32.7 per mille (Copeland, 1912; Craigie and Chase, 1918).

The maximum alteration that took place in the surface salinity at any one of these localities during the interval of from three to nine weeks was thus only 0.6 per mille; in most cases it was less than 0.2 per mille; several times it was too small to be measured, a statement covering both sides of the basin of the gulf as well as the coastal belt, and applying to one locality or another in three different years. Among the islands or off headlands where the tide runs strong the surface would not show this uniformity, because the salinity in such situations varies widely with the stage of the tide. Even if the observations were taken at the same stage of tide, variation would be expected with the varying interaction between current and wind. Upwellings, for instance, such as follow offshore winds (p. 588), will bring up water appreciably salter, as well as colder, from below, along the western shores of the Gulf of Maine, even if the updraft comes from a depth of only a few meters.

It is probable that the high salinity of the surface stratum recorded near Gloucester on July 9, 1912 (station 10001, 32 per mille) is to be explained on this basis. The salinity of the whole upper 40 meters, or so, of water may, in fact, be expected to vary considerably along the northern shore of the bay within brief periods, depending on the direction of the wind as this drives the surface water onshore or offshore. Unfortunately, however, our observations do not throw much light on the fluctuations in salinity of this sort, except on one occasion at a locality 3 to 5 miles off Gloucester, where the surface salinity, as calculated from hydrometer readings,[96] increased by about 0.7 per mille between July 9 and 11 in 1912, with a corresponding decrease of 4.5° in surface temperature, the latter usually a sure evidence of upwelling thereabouts. In the eastern parts of the gulf, however, where the water is more nearly homogeneous vertically, winds and tides affect the surface salinity chiefly by the on and off shore interchange of salter and less saline waters. Copeland (1912), for example, found the salinity of Passamaquoddy Bay varying with the tide (as well as locally in the bay) according to the relative outflow from the St. Croix River. Swirling tidal currents are also partly responsible for the regional variations recorded by Vachon (1918) and by Mavor (1923) in the surface salinity of Passamaquoddy Bay and of the Bay of Fundy, where, however, they also record a general increase in surface salinity during July and August, as follows:

Locality	Date	Salinity	Locality	Date	Salinity
		Per mille			*Per mille*
Friar Roads	July 25, 1916	31.48	Bay of Fundy, off Grand Manan, Prince station 3	Sept. 4, 1917	31.92
Do	Aug. 2, 1916	31.27	Passamaquoddy Bay, Prince station 4	July 20, 1916	30.36
Do	Aug. 19, 1916	31.73	Do	July 27, 1916	28.97
Do	Aug. 31, 1916	31.84	Do	Aug. 3, 1916	30.27
Bay of Fundy, off Grand Manan, Prince station 3	July 24, 1916	30.43	Do	Aug. 10, 1916	30.19
Do	Aug. 25, 1916	31.77	Do	Aug. 17, 1916	30.58
Do	July 4, 1917	30.61	Do	Aug. 31, 1916	30.77
Do	July 31, 1917	31.22			

In every August of record—1912 (Bigelow, 1914, pl. 2), 1913 (fig. 135), 1914 (fig. 136), or 1915 (fig. 137)—the surface salinity has been highest over the north-

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[96] Both taken with the same instrument

eastern part of the basin of the gulf, with the maximum near Lurcher Shoal in 1912 and 1915, over the northeastern deep as a whole and over German Bank in 1913, off Machias, Me., and on German Bank in 1914. Furthermore, the maximum reading for the month has varied little from year to year—32.84 per mille in 1912 (station 10031), 32.75 to 32.79 per mille in 1913 (stations 10094 to 10097), and 33.06 per mille in 1914.

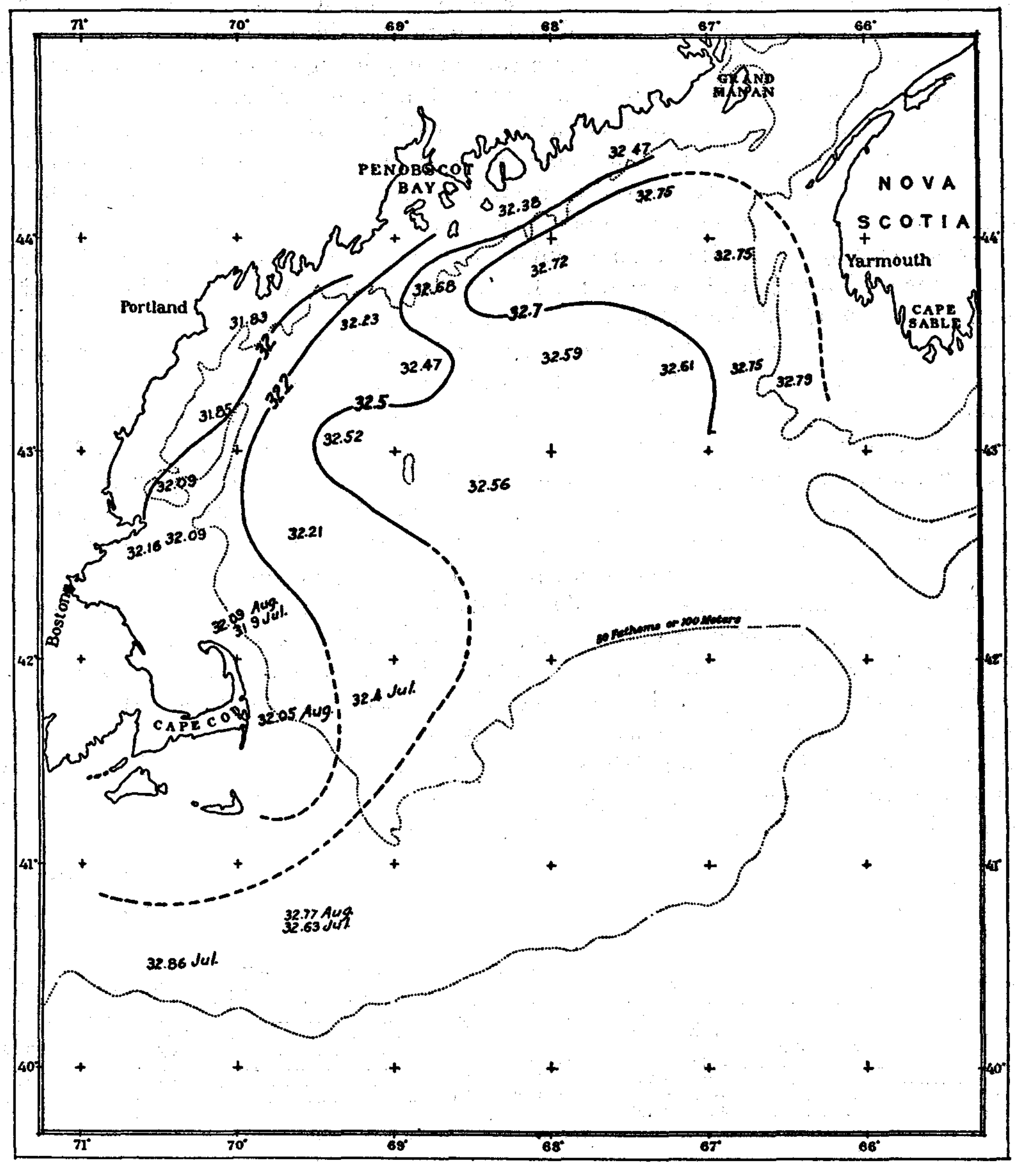

FIG. 135.—Salinity at the surface, August, 1913

A certain consistency also appears from year to year in the outlines of the area occupied by water salter than 32.5 or 32.7 per mille. In 1913 and 1914 this took the form of a U or V, its concavity directed toward the southwest, its one arm roughly paralleling and somewhat overlapping the 100-meter contour off the Nova Scotia coast, its other arm similarly paralleling the coast of Maine westward as far as the offing of Penobscot Bay (figs. 135 and 136). In my account of the salinities of 1913 I assumed that this saltest tongue was continuous with the still higher salinities outside the continental shelf via the southeastern part of the gulf (Bigelow, 1915, pl. 2). However, continued investigation of the gulf has made it more likely that this was actually an isolated pool surrounded by less saline water on the south, as was certainly the case in July and August, 1914 (fig. 136). This was

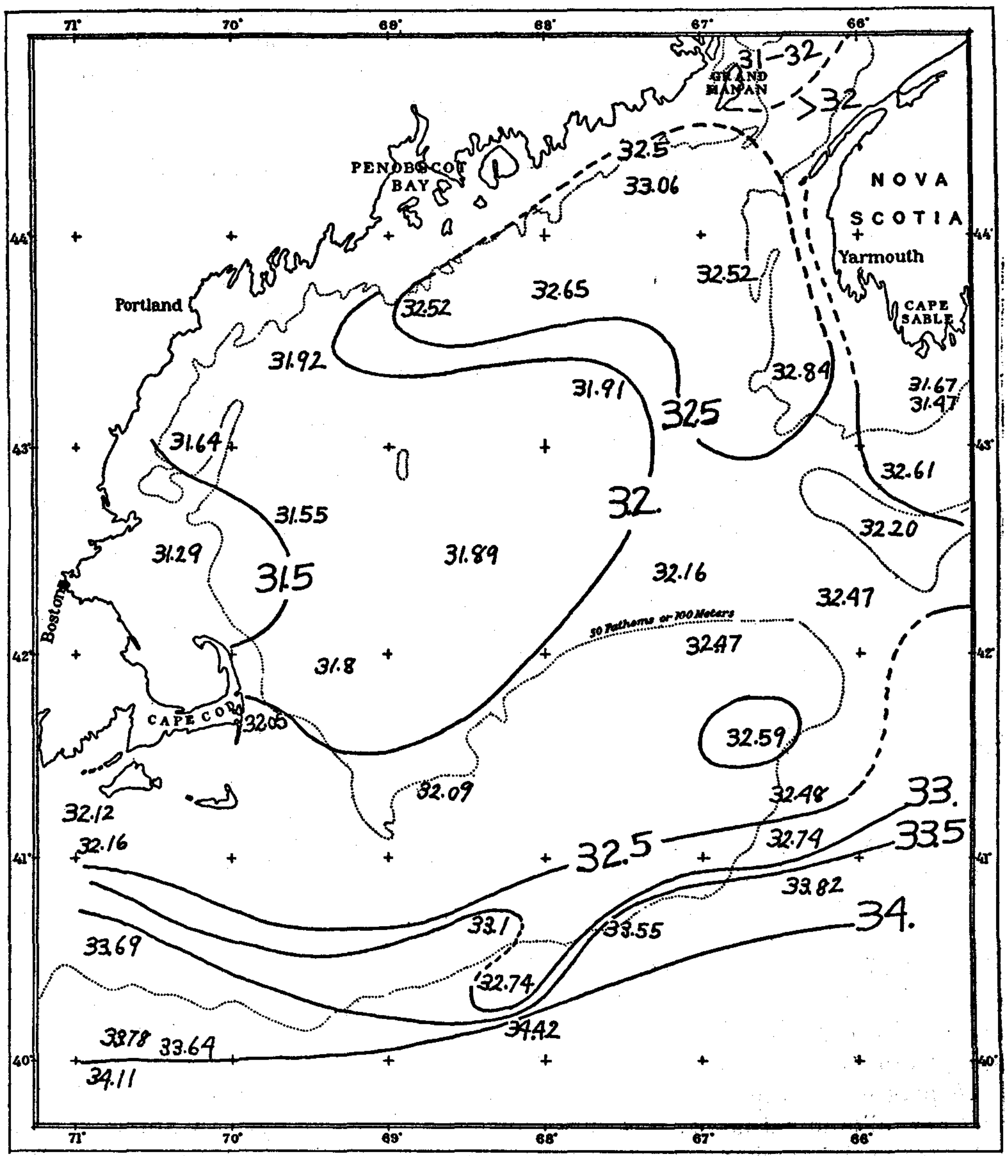

FIG. 136.—Salinity at the surface, July to August, 1914. For 32.61 in the northern channel read 32.01

again the case during August and the first few days of September in 1915 (fig. 137), when the surface was less saline than 32.5 per mille at all the eastern stations on the line Cashes Bank-Cape Sable, but more saline (32.6 to 32.8 per mille) farther north in the eastern arm of the basin.

Unfortunately, the stations for 1915 were not situated close enough together to locate the course of the isohaline for 32.5 per mille in a satisfactory manner; in the preliminary account of the operations for that season a reading of 32.52 per mille near Cashes Ledge (station 10308), with slightly lower salinities to the west of it as well as to the east (32.47 per mille at stations 20307 and 20309), was taken as evidence of a body of still salter water in the southern half of the gulf (Bigelow, 1917, p. 222, fig. 67). Further study of the salinities for the several years combined makes it more probable that the station in question marked the southwestern extremity of a band of 32.5 per mille that continued thence to the vicinity of Lurcher Shoal, as is indicated on the chart (fig. 137).

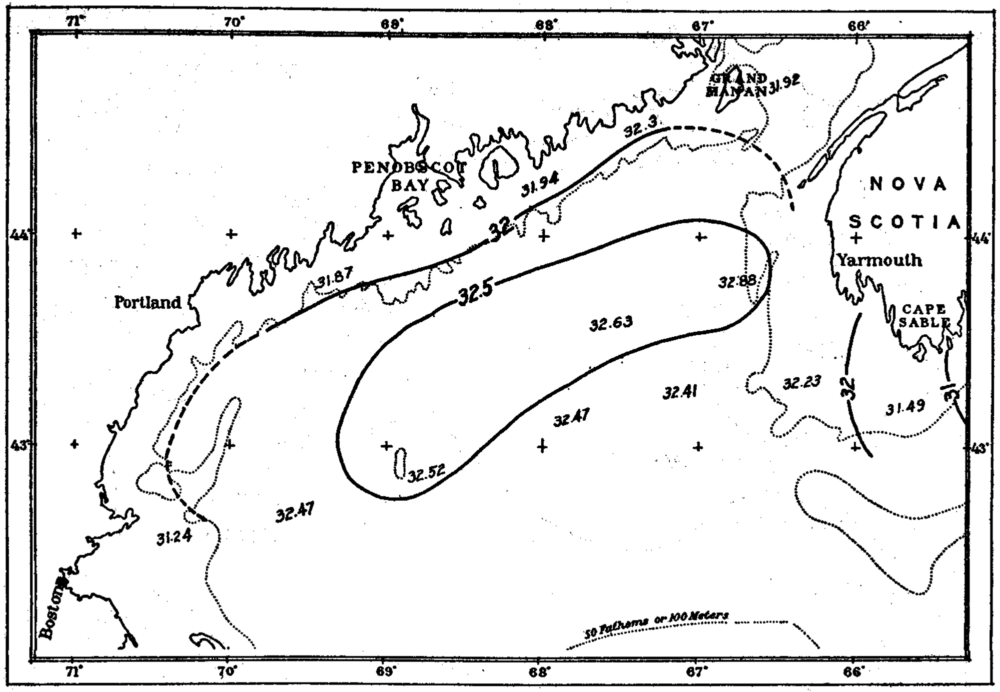

FIG. 137.—Salinity at the surface, August to September, 1915

A pool more saline than the surrounding water and usually very close to 32.75 to 33 per mille in actual salinity, may thus be expected to develop annually on the surface over the northeastern corner of the basin in August, its boundaries conforming more or less closely to the contour of the coastal slopes of Maine and of Nova Scotia but not involving the Bay of Fundy at all. Being entirely surrounded (in most summers, at least) by less saline water on the offshore as well as on the inshore side, it must obviously have its source in the still higher salinities below the surface as water is brought up by vertical currents of some sort, not in any direct indraft from offshore.

This salt pool had no counterpart in June (fig. 128) or in May (fig. 120) of 1915, but much smaller phenomena of the same sort were recorded off Lurcher Shoal in April, 1920 (station 20101, 32.9 per mille), in the southeastern part of the gulf and in the eastern part in that March (fig. 91). Thus, following the freshening characteristic of May (p. 745), the eastern side of the surface of the gulf is once more as salt by the end of August as at any time during the early spring.

Much lower values prevail along the west Nova Scotian shore all summer, Vachon (1918) having recorded 31.34 to 32.09 per mille on a line from Brier Island to Yarmouth on September 7, 1916, with readings of 31.17 per mille at high tide, 31.12 per mille at low tide, in Yarmouth Harbor on the 8th. It is on the strength of his data that the isohaline for 32 per mille is represented on the August chart (fig. 136).

To the eastward of Cape Sable the water next the coast is still less saline (31.7 to 31.6 per mille) in summer, with rather an abrupt west-east transition from higher to lower values off the cape. Essentially this is the same regional distribution as in June, except that the successive isohalines shift to the eastward during the early summer as the Nova Scotian current loses head. The constancy of this Nova Scotian water from month to month and from year to year also deserves mention, the lowest values recorded in the offing of Shelburne (including Bjerkan's (1919) data) ranging only from 30.9 to 32.1 per mille for the months of March, June, July, and September of the years 1914, 1915, and 1920. Sometimes these lowest values have been close in to the land off Shelburne, as was the case in July, 1915 (Bjerkan, 1919), and in September of that year (fig. 137); sometimes farther out, with higher values next the coast, as in July, 1914, and in March, 1920 (p. 703); but no definite seasonal succession is yet established in this respect.

The narrow band of water less saline than 32 per mille, which probably skirts the western coast of Nova Scotia every summer, is separated from the equally low salinities (31.2 to 32 per mille) of the northern side of the Bay of Fundy by considerably more saline surface water (32.3 to 32.4 per mille) along the southern (Nova Scotian) shore of the latter; such, at least, was the case in the summers of 1916 (Vachon, 1918) and 1919 (Mavor, 1923).

In each midsummer of record (1912, 1913, 1914, 1915) we have found the least saline surface water as a narrow but continuous band skirting the coast of Maine, and so southward to the region of Massachusetts Bay, usually 31 to 32 per mille in actual value. Inside the outer islands, and in the estuaries, still lower surface salinities are to be expected locally (e. g., 30.61 per mille in the western entrance to Penobscot Bay, August 3, 1912, station 10021a), grading, of course, to brackish water in the mouths of rivers. The definite boundary of this coastal water of low salinity (32 per mille) can not be laid down along the coasts of Maine and Nova Scotia on the chart for August, 1914 (fig. 136), because most of our stations for that year were located outside the 100-meter contour. In this respect the chart for 1913 (fig. 135) is more instructive.

In the northwestern part of the gulf variations in the distribution of salinity from summer to summer show that the movements of the surface water are variable in detail.

Thus, in July and August, 1912, the isohaline for 32.4 per mille (the critical one in this particular summer) marked a definite expansion of coastal water off Penobscot Bay (Bigelow, 1914, pl. 2). In August, 1913 (fig. 135), the undulations of the isohaline for 32.5 per mille again suggested an anticlockwise swirl off the bay, drawing salter water into its northern and eastern sides, fresher water into its western and southern sides. In August, 1914 (fig. 136), the surface salinity of this part of the gulf was more uniform, with no evidence of any such outflow off the Penobscot; nor is anything of the sort indicated in the surface chart for 1915 (fig. 137).

In the Massachusetts Bay region, by contrast, the regional distribution of salinity at the surface has been more nearly constant from summer to summer. Thus, in August, 1922 (apparently a representative year in this respect), when the surface at 13 stations ranged from 30.95 to 31.29 per mille, the distribution was of the usual coastwise type—i. e., slightly lowest (30.9 to 31 per mille) close to Gloucester (station 10633), off the mouth of Boston Harbor (station 10638), and close to land in Cape Cod Bay (stations 10643 and 10644); uniformly slightly higher across the mouth of the bay (31.2 per mille at stations 10631 and 10632). Three stations on a line crossing the mouth of the bay on August 31, 1912, showed no greater variation than this on the surface, though all of them gave slightly higher readings (31.67 to 32.03 per mille). It is probable that the surface of the bay would have been found less saline than this in August, 1916, judging from a surface reading of 31.27 per mille off the tip of Cape Cod on the 29th (station 10398) and from the fact that the mouth of the bay had been only 30.5 to 31.2 per mille a month earlier (stations 10340 to 10342). In 1913 the August value was somewhat higher at the mouth of the bay—i. e., about 32.1 per mille.

Observations taken in the offing of Nantucket and on the northwestern part of Georges Bank in July of 1913, 1914, and 1916 show all this area included within the influence of the low salinity of the coastal belt, with surface values close to 32 per mille over Nantucket Shoals, rising to 32.1 to 32.5 per mille over the neighboring parts of Georges Bank (fig. 136; Bigelow, 1922, fig. 36). Surface readings make it probable that in July, 1914 (fig. 136), the band of low temperature described above (p. 608) as crossing the bank from northeast to southwest was reflected in an expansion of low salinity from the southwestern part of the bank out across its seaward slope, as outlined by the isohaline for 33 per mille.

It is probable that the regions of low surface temperature over the shoaler parts of Georges Bank, where the water is churned by strong tidal currents (p. 594), are equally characterized by a surface salinity higher than that of the general neighborhood. Our visits thither have afforded two instances that may be interpreted in this way—namely, a slightly higher value at one station on the eastern part (32.59 per mille at station 10223) on July 23, 1914, than at neighboring stations to the north, south, or east of it, and a value equally high on the western side on the same date of 1916 (station 10348, 32.54 per mille), again with slightly less saline surface water to the south, west, and apparently to the north. A similar pool of high surface salinity (presumably about 32.5 per mille) is also to be expected over the shoal part of the bank and near its northern edge.

Very considerable fluctuations are to be expected in the salinity of the surface along the edge of the continent abreast of the Gulf of Maine, as well as in its temperature (p. 596), as the oceanic water of high salinity approaches the banks or recedes from them.

In the southwestern part of the area, in the offing of Marthas Vineyard, the data for July, 1916, August, 1914, and for autumn (p. 801) make it reasonably certain that surface water as saline as 33 per mille normally drifts in over the outer part of the shelf during July and the first three weeks of August, but seldom (perhaps never) approaches much nearer the shore than is represented on the chart for 1914 (fig. 136).

Farther to the east the isohaline for 33 per mille may be expected to skirt the southern edge of Georges Bank in July, lying a few miles farther in in some summers, farther out in others, and crossing the oceanic triangle between Georges and Browns Bank, but not, in our experience, encroaching at all over the latter. Still farther eastward surface water as saline as 33 per mille overflows the edge of the continent in July or August of some years, as in 1915, when Bjerkan (1919) had still higher readings (34.27 per mille) at the 400-meter contour in the offing of Cape Sable on July 22. In 1914, however, the surface water near by was only 31.22 per mille a week later in the season (station 10233), though the difference in date would suggest a difference in salinity of just the reverse order, evidence of considerable fluctuation in this respect from summer to summer.

It is doubtful whether surface water as salt as 34 per mille ever encroaches on the edge of the continent abreast of the Gulf of Maine; certainly we have no record of such an event at any season, but the surface charts for the winter, spring, and summer (figs. 93, 127, and 136) show that it is to be expected only a few miles out from the 200-meter contour south of Marthas Vineyard and off the western end of Georges Bank by the first half of July in early seasons, but perhaps not until August in late seasons. In some summers, as in 1914, water of this high salinity lies farther out from the edge of the continent to the eastward. In other summers, however, it evidently spreads shoreward over the slope off Shelburne as early in the season as it does farther west—witness the records obtained by the Canadian Fisheries Expedition in 1915, mentioned above (Bjerkan, 1919; *Acadia* station 41).

None of our lines have run far enough out, abreast the gulf, to reach surface water of full oceanic salinity (35 per mille and upwards); nor is it known how far out from the edge of the continent water of 34 per mille withdraws in winter and spring.

ANNUAL VARIATIONS IN SURFACE SALINITY IN SUMMER

Passing reference has been made in the preceding pages to the variations that have been observed in the salinity of the surface from summer to summer. The most interesting fluctuation of this sort that has come to our attention is that surface values averaged much lower in the southwestern part of the region in July, 1916, than in that same month in 1912, 1914, or 1915; the surface of Massachussetts Bay, for instance, was about 1 per mille less saline on July 19 to 20, 1916, than at about the same dates in 1912 or in 1915. Probably the correct explanation is that 1916 was a tardy spring, when the effect of vernal freshening from the land continued evident until later in the season than usual, and when the approach of water of high salinity to the continental shelf was delayed until later in the season. As a result of this retardation of the vernal cycle—associated, no doubt, with the severity of the preceding winter and the lateness of the spring—the salinity of the surface was very nearly uniform on July 24, 1916, right across the whole breadth of the western end of Georges Bank, where a considerable north-south gradation is to be expected at that season in more normal years (fig. 136).

Contrasting with 1916 and with 1914, the summers of 1912 and 1913 may be characterized as "salt" in the western side of the gulf, with surface values averaging about 0.1 to 1 per mille higher at corresponding localities and dates than in 1914—August as well as in July—but with very little difference from summer to summer in the eastern side. The surface values for 1915 paralleled those for 1914 except for the closer approach of oceanic water to the continental shelf off Nova Scotia, mentioned above (p. 771).

No wide annual fluctations in salinity have been recorded for any part of the gulf at a given season, or are such to be expected.

VERTICAL DISTRIBUTION

The salinity of the deep strata of the gulf, like that of the surface, remains more nearly constant during July and August than over any period of equal duration earlier in the summer or in the spring. Two stations in the basin off Cape Cod, four weeks apart in 1914 (stations 10214 and 10254, July 19 and August 22), exemplify this for the western side of the gulf, the values, depth for depth, being nearly alike in spite of the time interval separating them, with the one station slightly the more saline at some levels, the other at other levels.

The graph (fig. 138) illustrates how little variation in salinity has been recorded for the deeper levels in the western side of the basin at different dates in August of different years, individual stations seldom differing by more than 0.2 to 0.4 per mille in either direction from the mean values of 32.6 per mille at 50 meters, 33 per mille at 100 meters, 33.4 per mille at 150 meters, 33.9 per mille at 200 meters, and about 34.1 per mille at 250 meters.

Except in localities where the tide runs strong enough to keep the whole column of water thoroughly mixed from top to bottom, the salinity of the gulf is invariably lower at the surface in summer than on the bottom, as already stated for the spring months. I should emphasize, also, that the increase in salinity with depth is continuous, or at most is interrupted by homogeneous strata; we have never found fresher water underlying salter in the gulf. Thus, the intermediate layer of low temperature, characteristic of certain summers (p. 602), is not reproduced by the salinity; but the vertical distribution varies widely from place to place in the gulf, a convenient division in this respect being (1) into the coastal zone, (2) into the basin, and (3) into the offshore rim.

In the western section of the coastal zone, out to the 100-meter contour, the vertical increase of salinity, with increasing depth, averages much more rapid in the upper stratum than at greater depths, with most of our stations showing a vertical range of 0.6 to 1 per mille between the surface and the 40 to 50 meter level (fig. 139). Eastward from Penobscot Bay we have found a more uniform gradient of salinity from the surface downward, as illustrated by stations near Mount Desert Island (fig. 107).

Throughout the sector between Cape Cod and Mount Desert the difference in salinity between the surface and the 40 to 50 meter level is everywhere considerable in summer (though less than in spring, p. 728)—perhaps nowhere less than 0.3 per mille in July or August, with a maximum vertical range of about 1 per mille in the Massachusetts Bay region within these depth limits.

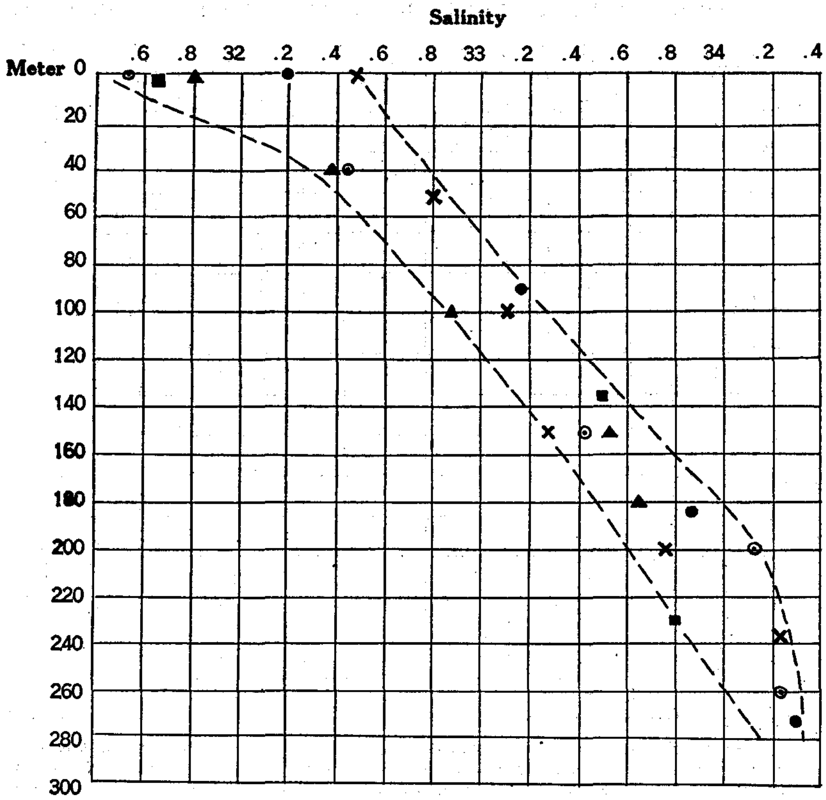

Fig. 138.—Vertical distribution of salinity in the western side of the basin, in the offing of Cape Ann, in July and August of different years. ●, August 9, 1913 (station 10088); ⊙, August 22, 1914 (station 10254); ▲, August 23, 1914 (station 10256); X, August 31, 1915 (station 10307). The broken curve marks the approximate limits to annual variation

Passing eastward from Mount Desert toward the Bay of Fundy, the vertical range of salinity is progressively narrower and narrower, corresponding to the more and more active tidal stirring. In the Grand Manan Channel so close an approach to verticle homogeneity is maintained throughout the summer that the maximum vertical range so far recorded for August has been only about 0.08 per mille, as follows:

Station	Date	Depth	Salinity
		Meters	*Per mille*
10035	Aug. 19, 1912	0	32.57
10035	do	82	32.65
Mavor's No. 27	Aug. 27, 1919	0	32.01
Do	do	85	32.09
Mavor's No. 28	do	10	32.14
Do	do	80	32.20

Vachon's (1918) and Mavor's (1923) determinations show that the vertical distribution of salinity within the Bay of Fundy varies regionally in summer, probably depending on local and temporal variations in the strength of the tidal streams. Where the water is least stirred vertically, and where the surface is least saline because most subject to the freshening effect of the outflow from the St. John River, the salinity of the upper 40 to 50 meters very closely parallels that of the mouth of Massachusetts Bay (fig. 139) and of the western side of the gulf generally, grading from this to the vertical uniformity characteristic of the Grand Manan Channel.

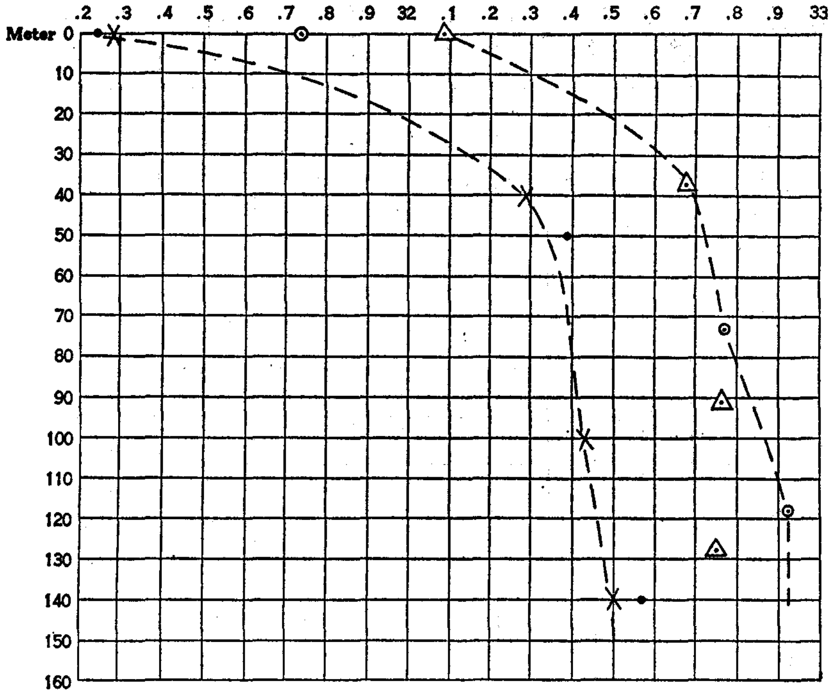

FIG. 139.—Vertical distribution of salinity in the deep bowl off Gloucester in July and August of different years. ⊙, July 10, 1912 (station 10002); △, August 9, 1913 (station 10089); ×, August 22, 1914 (station 10253); ●, August 31, 1915 (startion 10306). The broken curves mark the approximate limits of annual variation

Strong tidal currents are similarly responsible for a close approach to vertical homogeneity over German Bank in August as in spring (p. 748) and early summer (p. 756), the greatest difference between the surface and the bottom at any of our summer stations there being only about 0.3 per mille, as follows:

Salinity on German Bank, August to September

Station	Date	Depth	Salinity	Vertical range
		Meters	*Per mille*	*Per mille*
10029	Aug. 14, 1912	0 64	32.70 32.92	0.22
10065	Aug. 12, 1913	0 55	32.75 32.94	.19
10244	Aug. 12, 1914	0 55	32.84 32.90	.06
10311	Sept. 2, 1915	0 65	32.23 32.56	.33

In the deeper parts of the gulf the vertical distribution of salinity at depths greater than 50 to 70 meters depends less on the tide (very active tidal stirring is for the most part confined to the shoaler parts of the gulf) than on the configuration of the bottom, as affecting the free circulation of the water of high salinity that drifts into the basin via the trough of the Eastern Channel. One extreme is illustrated by the deep bowl or sink off Gloucester, where a depth of 181 meters is inclosed by a rim rising to within about 75 meters of the surface at its deepest point. Here, on each of our summer visits (figs. 104 and 139), we have found a very rapid increase in salinity with depth down to the 40 to 50-meter level, succeeded by a much more gradual increase from that depth down to the bottom. More concretely, the maximum vertical range between 40 meters and bottom has been only about 0.2 per mille here at any summer station, contrasting with a range of 0.6 to 1 per mille of salinity between the surface and the 40-meter level. Evidently the submarine rim of this bowl is so effective a barrier that the water inclosed by it is

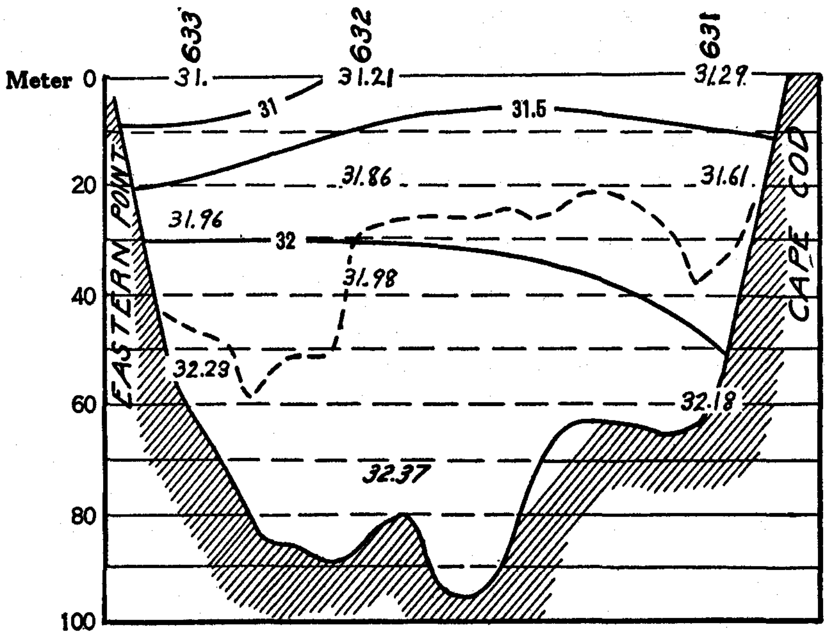

FIG. 140.—Salinity profile crossing the mouth of Massachusetts Bay, Gloucester to Cape Cod, just west of Stellwagen Bank, August 22, 1922. The broken curve is the contour of the bank

but little influenced by the slope water in the bottom of the basin near by, but continues through the summer at about the same salinity that characterizes the overlying stratum in early spring.

Stellwagen Ledge, at the mouth of Massachusetts Bay, also isolates the deeper water behind it to some extent, as shown by the correspondence between the contour of the bank and the isohaline for 32 per mille on the profile for August, 1922, and by the homogeneity of the deeper water contrasted with the wide vertical range in the shoaler strata (fig. 140).

Although the deep sink to the west of Jeffreys Ledge is open to the north, where its rim has a depth of about 134 meters, the narrowness of the opening on this side combines with the north-south direction of the axis of the ledge and with the shoalness (48 to 64 meters) and comparative steepness of the latter to hinder the drift of bottom water westward from the open basin of the gulf. Two stations in the trough for August 15, 1913, are especially interesting in this connection because the southern (inner) one of the pair was nearly homogeneous in salinity at depths greater than 50 to 60 meters, though the outer one showed a rapid increase in salinity from the surface downward to a depth of about 90 meters. Evidently comparatively little interchange was then taking place along the trough in the deep strata.

Sometimes, however, bottom water of high salinity does drift inward, around the northern end of Jeffreys Ledge, into this trough in much greater volume; as in August, 1914, for instance, when a difference of 0.4 per mille in salinity was recorded between the 40 to 50 meter level and the bottom (station 10252).

The relationship between the deep strata of the Bay of Fundy and the basin outside, from which it is separated by a low submarine ridge, is of this same order in summer, with the vertical rise in salinity much more rapid above than below the 50 to 70-meter level in the bay (Mavor, 1923), whereas the increase in salinity with depth in the basin off its mouth is most rapid near the bottom (fig. 114).[97] A difference in vertical distribution of this sort shows as clearly as does the much higher salinity (34 per mille) of the bottom of the basin that only a small amount of water from the deeps of the latter was then entering the bay.

The distribution of salinity has been more uniform, regionally, at most of our summer stations in the inner parts of the basin of the gulf down to a depth of about 200 meters. In the western branch, where the superficial stratum is influenced by the dispersal of land water, slight geographic differences in the locations of the stations and secular changes in the surface currents produce corresponding differences in the curves for salinity, depending on the precise state of the surface water. At greater depths the vertical salting may either continue at an undiminished rate right down to the bottom, as was the case on August 31, 1915 (station 10307, fig. 138), or the deepest stratum (more saline than 34 per mille) may form a homogeneous blanket on the bottom, 50 to 60 meters thick, as we found it on August 22, 1914 (station 10254, fig. 112).

A much thicker and considerably more saline (35 per mille) layer had blanketed the bottom of the southeastern part of the basin a month earlier that summer (station 10225, fig. 131), but with the salinity increasing rapidly with depth in the

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[97] Stations 10097 (August, 1913), 10246 (August, 1914), and 10304 (August 6 and 7, 1915).

shoaler strata of water, reproducing the vertical distribution found there (though somewhat more saline in actual values) in March and April of 1920 (stations 20064 and 20112), hence this type is probably characteristic of that part of the gulf.

The state of the deep water in the two channels—eastern and northern—that interrupt the offshore rim of the gulf is worth stating, these being the possible sources for deep undercurrents flowing inward. In July, 1914 (our only late summer stations for this locality), the vertical distribution of salinity was almost precisely the same in the Eastern Channel as in the southeastern part of the gulf, into which the latter debouches, as were the actual values at different depths, with so little difference between the values in the channel for the months of March, April, June, and July in different years (fig. 141) as to prove the salinity of its deeper strata virtually unchanging there through spring and summer. The Northern Channel, on the other side of Browns Bank, at the same date (station 10229, July 25, 1914), was about 1.5 per mille less saline than the Eastern Channel on bottom (100 meters), though only about 0.5 per mille less so at the surface.[98] Consequently, any drift over the bottom via this route would have brought water much less saline to the gulf, as is also the case in spring (fig. 99).

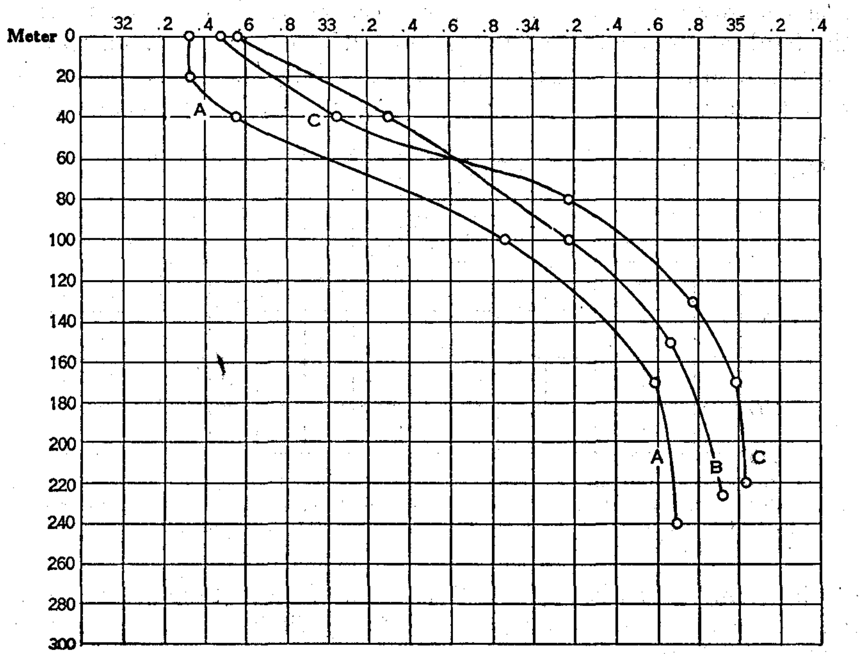

FIG. 141.—Vertical distribution of salinity in the Eastern Channel. A, April 16, 1920 (station 20107); B, June 25, 1915 (station 10297); C, July 24, 1914 (station 10227)

Our late summer stations yielded almost precisely the same salinity on Browns Bank (station 10228) as in the Eastern Channel to the west of it and in the neighboring part of the basin of the gulf, correspondingly salter than the Northern Channel to the north (cf. fig. 141 with fig. 142), evidence of an overflow from the Eastern

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[98] 32.47 per mille at the surface at station 10227; 32.01 per mille at station 10229.

Channel as the normal seasonal sequence to the late June state of 1915, a type of circulation also suggested by a corresponding rise in bottom temperature on Browns Bank (p. 619).

Much lower salinities, however, on the neighboring parts of Georges Bank at this same date [90] are equally clear evidence that no drift had taken place westward from the channel; nor have we ever found any indication of an overflow in that direction.

It is probable that offshore water encroaches over the outer edge of Georges Bank to some extent during most summers, at deeper levels as well as at the surface (p. 771), an event made evident in 1914 by the very high salinity of the bottom water (34.9 per mille) on its southwest part on July 20 (fig.142, station 10216). The effect of this highly saline water, however, was so closely confined to the southern side of the bank at the time, that a station on its northern part, only 42 miles away (station 10215) showed no evidence of it, the salinity not only being much lower (32.09 to 32.9 per mille) but the whole column much more nearly homogeneous surface to bottom. Nor did any overflow from offshore take place farther east on Georges Bank in 1914 up to the last week of July (if it ever does), although water of 34 to 35 per mille then washed the bottom below the 100-meter contour all along the outer edge of the bank (stations 10217, 10219, 10221, and 10222).

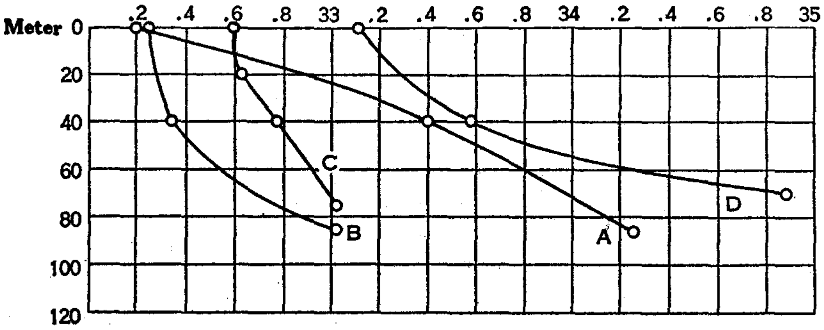

FIG. 142.—Vertical distribution of salinity on the offshore banks in July, 1914. A, Browns Bank, July 24 (station 10228); B, northeast part of Georges Bank, July 24 (station 10226); C, eastern part of Georges Bank, July 23 (station 10223); and D, southwestern part of Georges Bank, July 20 (station 10216)

In summers when the seasonal cycle is more backward (1914 seems to have been rather a forward year in this respect) oceanic water may not encroach on the bottom on any part of Georges Bank before August and perhaps not then. In 1916, for example, two stations on the western and southwestern parts of the bank (10347 and 10348) gave no evidence of any such event on July 23, the salinity being nearly uniform vertically at both, its value (32.4 to 32.6 per mille) no higher than the mean for the whole column on the northern parts of the bank at about that same date in 1914.

Wide regional variations in salinity are to be expected over the broken bottom of Nantucket Shoals, depending on the strength and on the mixing effects of the tidal

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[90] Station 10223 and 10224, 32.6 to 33.03 per mille in 55 to 75 meters; fig. 142.

currents. Unfortunately, no stations have been occupied there at the more tide-swept localities, where salinity, like temperature (p. 605), is probably kept nearly homogeneous vertically throughout the summer. A difference of 0.41 per mille of salinity between the surface (31.73 per mille) and the bottom (32.14 per mille, depth 30 meters) was recorded on the southwestern edge of the shoals on July 25, 1916 (station 10355), with about this same vertical range at a station close to Nantucket Lightship on July 9, 1913 (station 10060; salinity 32.63 per mille at the surface, 32.04 per mille at 46 meters). A vertical distribution of this same sort has prevailed in shallow water off Marthas Vineyard in July and August (stations 10356 and 10357, July 26, 1916; 10258 and 10263, August 25 and 27, 1914), the water as usual saltest on bottom.

Farther out on this sector of the shelf, where the vertical distribution varies at any given locality and date according to what overflow of oceanic water has recently taken place and at what level, the mid depths may be less saline than either the surface or bottom, as was the case at station 10259 on August 25, 1914. However, there is every reason to suppose that such a state is exceptional and probably transitory, and that the vertical distribution is usually of the same type there (freshest at the surface, saltest on the bottom; fig. 143) as it is nearer the land and within the Gulf of Maine.

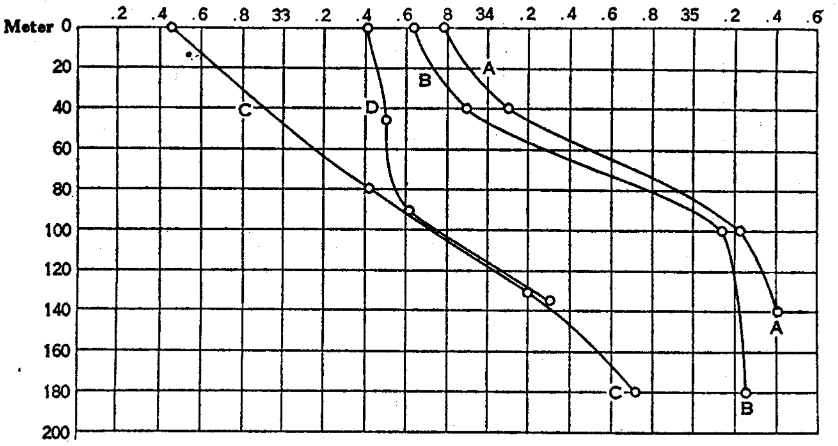

FIG. 143.—Vertical distribution of salinity on the outer part of the continental shelf off Nantucket and Marthas Vineyard. A, August, 1914 (station 10260); B, August 26, 1914 (station 10262); C, July 24, 1916 (station 10351); D, July 10, 1913 (station 10061)

Our summer stations outside the edge of the continent, whether abreast of the Gulf of Maine or a few miles to either side of the meridians bounding the latter, have all shown a very rapid increase in salinity with increasing depth in the superficial stratum (fig. 144), though with wide differences in the actual values from station to station. In part these differences depend on whether the oceanic water lies far out from or close in to the banks at the time, but also on the precise location of the stations in question, because the transition from banks to ocean is so abrupt along this zone that a difference of half a dozen miles in geographic position may be accompanied by a very wide difference in the salinity of the surface water as well as in its temperature (p. 605).

As stated, 1916 was so tardy a summer that the very close agreement between the curves off Georges Bank for that July (station 10352) and off Cape Sable in July, 1914 (station 10233, fig. 144), is deceptive; equal salinities are usually attained about a month later in the season off the eastern portal to the gulf than off the western.

When the highly saline water of the ocean basin moves closest in toward the edge of the continent, whether to the east or to the west of the Eastern Channel (p. 771), a very characteristic vertical distribution results, with the values highest at a depth of 40 to 100 meters. Station 10218, off the southwest slope of Georges Bank (our most oceanic station in temperature as well as in salinity), showed such a distribution on July 21, 1914 (fig. 144), with a maximum salinity approximating full oceanic value (36.04 per mille) at 40 meters, though with the surface water much less saline (34.42 per mille). Stations a few miles farther east along the slope, the

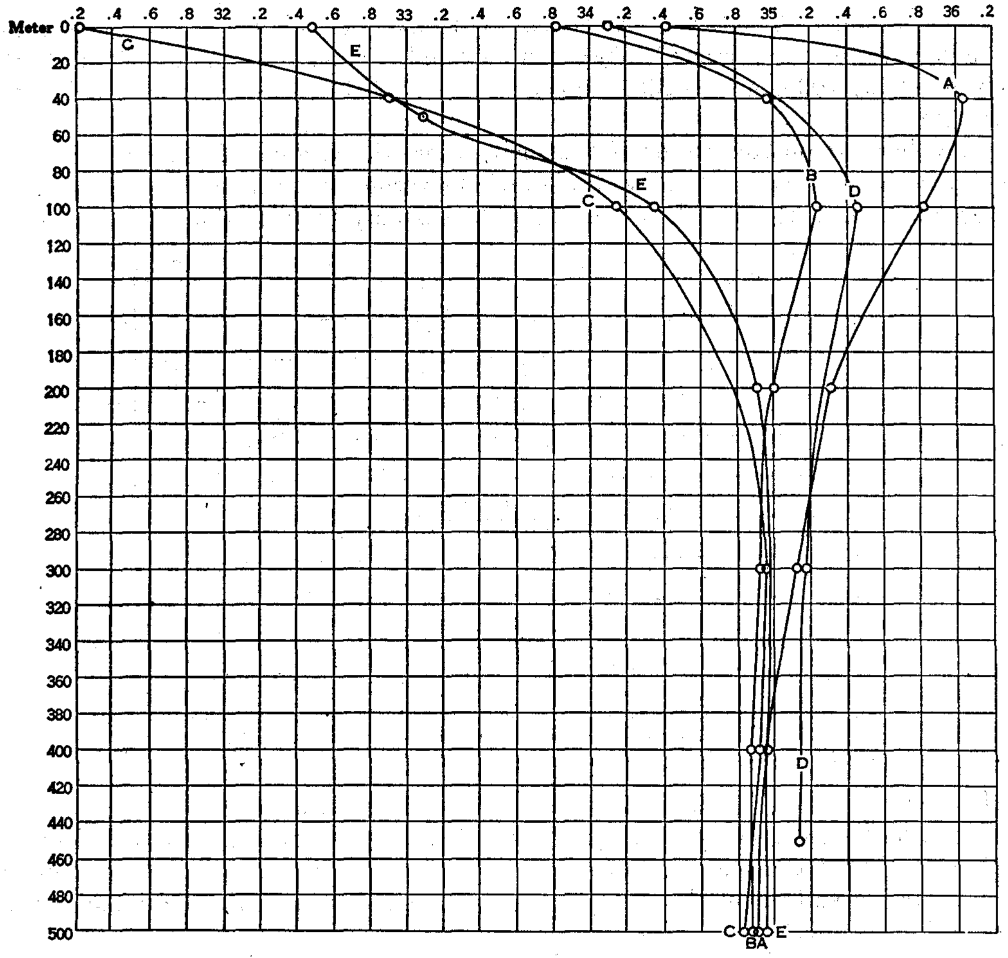

FIG. 144.—Vertical distribution of salinity along the continental slope abreast of the Gulf of Maine in summer. A, southwest slope of Georges Bank, July 21, 1914 (station 10218); B, southeast slope of Georges Bank, July 22, 1914 (station 10220); C, abreast of Shelburne, Novia Scotia, July 28, 1914 (station 10233); D, south of Marthas Vineyard, August 26, 1914 (station 10261); E, southwest slope of Georges Bank, July 24, 1916 (station 10352)

next day (10220), and at the same relative position off Marthas Vineyard on the 26th of that August (10261), yielded salinity sections similar in type (fig. 144), though with actual values considerably lower in the upper 150 meters. The bottom water at all these stations has been close to 35 per mille at depths greater than 300 meters.

None of our stations have been located far enough out from the edge of the continent to show the true tropical-oceanic distribution of salinity—namely, saltest at or very close to the surface and decreasing with increasing depth down to 600 to 1,000 meters. Curves of this sort result, for example, from the observations taken by the United States Coast Survey steamer *Bache* on her profile from Bermuda to the Bahamas in January, 1914 (Bigelow, 1917a, figs. 8 and 9), and by the *Dana* near Bermuda in May, 1922 (Nielsen, 1925, fig. 5); but when the so-called "inner edge of the Gulf stream" approaches the edge of Georges Bank, as in July, 1914, doubtless one need run off only a few miles into the oceanic basin to find the salinity so distributed there.

GENERAL DISTRIBUTION OF SALINITY BELOW THE SURFACE

The spacial relationships of the differences in salinity just outlined and the general state of the gulf in summer are made more graphic by the usual projections—horizontal and profile.

The salting of the eastern side of the gulf, which takes place from June to August (p. 765), contrasted with the freshening of the western side of the basin as land water is dispersed seaward (p. 763), produces a decided alteration in the distribution of salinity from late spring through the summer at moderate depths as well as at the surface (p. 763). In 1915 these changes resulted in an increase in the salinity of the 40-meter level from about 32.5 per mille to about 32.8 to 33.5 per mille in the northeastern part of the basin during the interval between the last week of June (fig. 133) and the end of August, contrasting with a decrease in its western side from about 32.9 per mille to about 32.6 per mille, though very little seasonal alteration took place meantime in the coastal zone near Mount Desert, on the one hand (about 32.3 per mille), or near Cape Sable on the other (about 31.9 per mille).

The most interesting feature of the 40-meter chart for July and August, 1914 (fig. 145), which may be taken as typical of the season (there being no reason to suppose that this was either an abnormally fresh or an abnormally salt year), is the regular gradation from low values in the western side of the gulf to a tongue of high salinity (33+per mille) in the eastern side of the basin, again giving place to a narrow zone of much fresher water along western Nova Scotia, with still lower values (31.8 per mille) near Cape Sable and eastward along the outer coast of Nova Scotia (Bigelow, 1917, fig. 33).

A much wider extent of 33 per mille water in that August than is shown on the May and June charts for 1915 (figs. 125 and 133) no doubt reflects some seasonal drift inward from the Eastern Channel after the slackening of the Nova Scotian current, with the isohaline for 32.9 per mille revealing a tendency for the saltest band to circle westward along the coastal slope of Maine, bringing salinities as high as 32.9 to 33 per mille as far as the offing of Penobscot Bay. A tongue of this same sort and of about the same salinity (33 to 33.2 per mille) also characterized the 40-meter level in August, 1913 (fig. 146); and while the most saline water (33 per mille) did not form so definite a tongue in 1912 (Bigelow, 1914), a regional distribution of the type just described has reappeared frequently enough on the charts for various levels, months, and years to establish it as normal for the gulf.

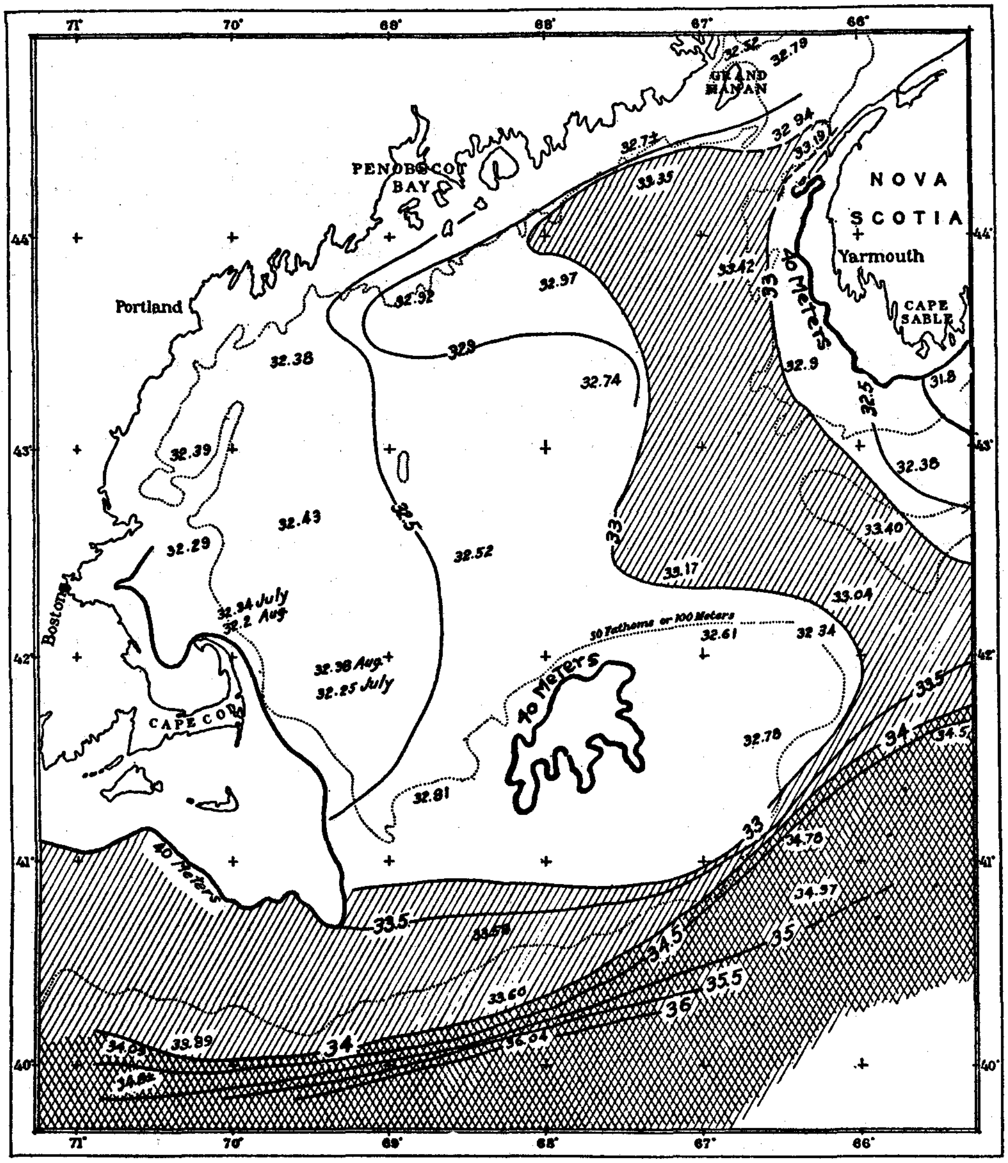

FIG. 145.—Salinity at a depth of 40 meters, July 19 to August 24, 1914

Densities determined by Craigie (1916a) for August 27 to 29, 1914, when reduced to terms of salinity also show this saline water (33 per mille) curving into the southern side of the Bay of Fundy along its Nova Scotian side, with a regular decrease in salinity from south to north across the bay to about 32.5 per mille near Campobello Island. Recurrence of a regional distribution of this same sort in the bay in August, 1916 (Vachon, 1918) and 1919 (Mavor, 1923), proves it characteristic of the 40-meter level there at the end of the summer, though the actual values were somewhat lower in those two years than in 1914.

Corresponding to the contraction of the area of the gulf with increasing depth, this salt tongue gives place to a gradation from low salinity to high across the basin from west to east at deeper levels, as illustrated by the 100-meter chart for July and August, 1914 (fig. 147), on which the successive isohalines (33 and 33.5 per mille) outline the same eddying movement of the saltest water westward, past the offing of Penobscot Bay, as at 40 meters (p. 781). Some west-east gradation of this sort has been recorded on each of our August cruises at the 100-meter level; but the actual difference in salinity between the highest values in the eastern side of the gulf and the lowest in the western side was much wider in 1914 than in 1913 when the regional range was only from about 33.1 to about 33.5 per mille at 100 meters, with the whole west-central part of the basin close to uniform, regionally, at 33.1 to 33.3 per mille (fig. 148).

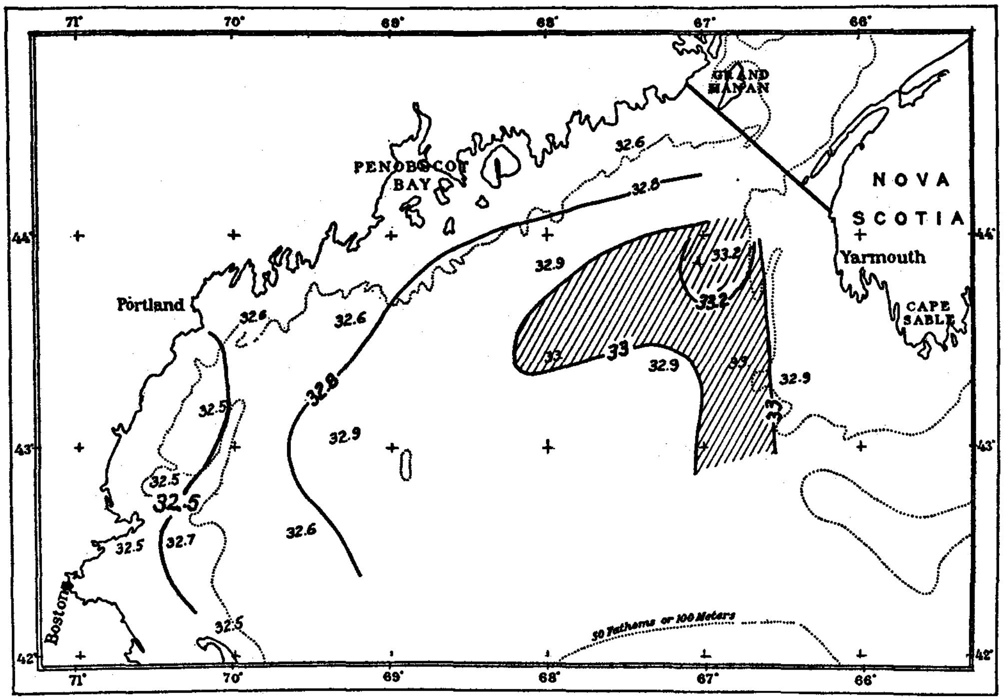

FIG. 146.—Salinity at a depth of 40 meters, August 5 to 20, 1913

The gradual absorption of the indraft from the Eastern Channel into the general complex of the gulf is more clearly illustrated on the 100-meter chart for 1914 (fig. 147) than at shoaler lines by the successive decrease in salinity, passing inward from the channel (34.4 per mille), to about 33.6 per mille in the northeastern corner of the gulf.

At still deeper levels the distribution of salinity becomes increasingly governed by the contour of the bottom as this more and more confines the inflowing slope water. Thus the latter (34 per mille) was not only directed more into the eastern arm of the Y-shaped trough at 175 meters than into the western in 1914 (fig. 149), but hugged the eastern slope of the former, making it the site of an anticlockwise

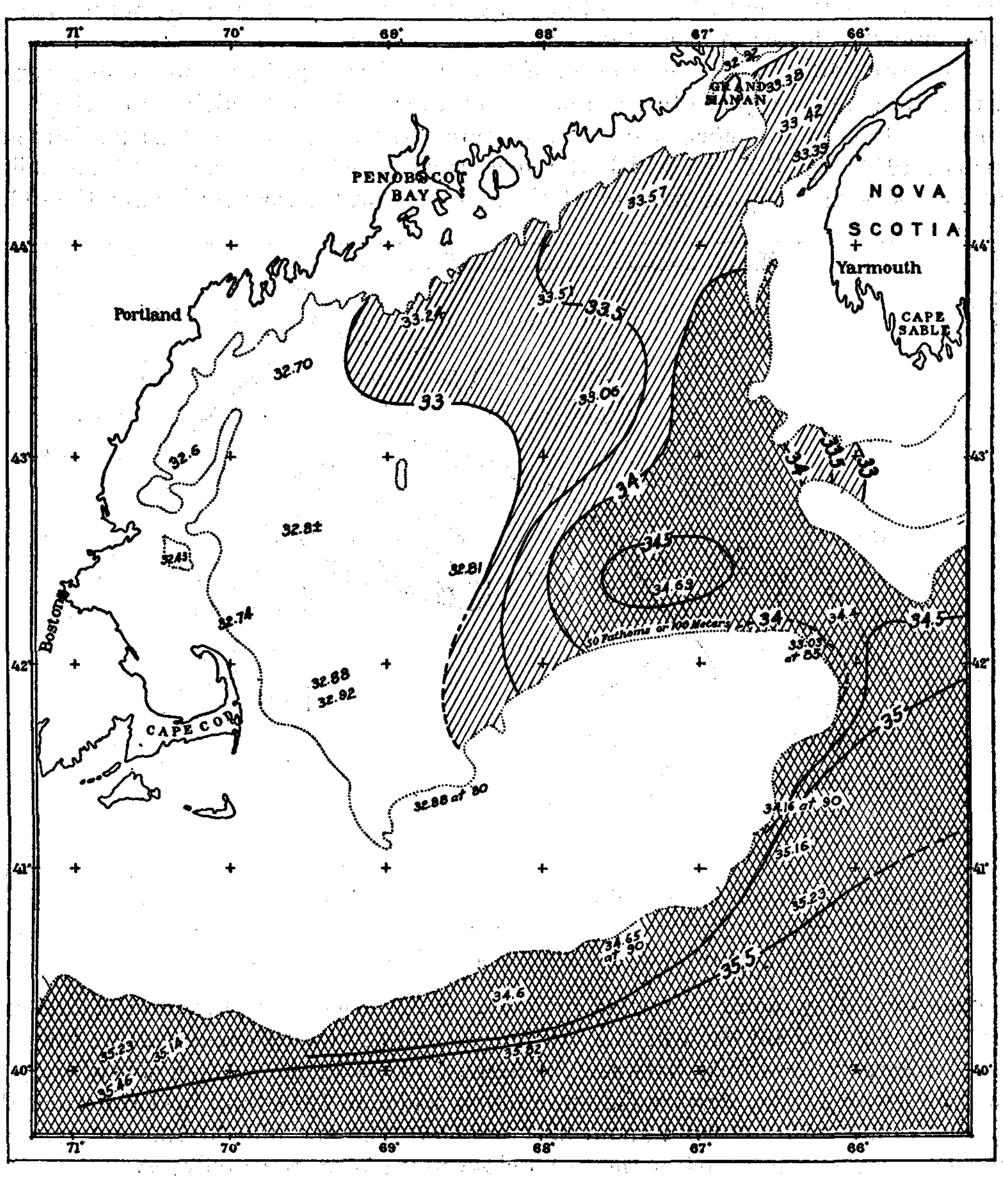

FIG. 147.—Salinity at a depth of 100 meters, July 19 to August 26, 1914. Bay of Fundy from Craigie

circulation. This seems also to have been the case in 1912,[1] with absolute values varying from 34.3 per mille in the extreme northeast, off Machias, Me. (10036), to 33.5 per mille in the depression between Platts Bank and Cashes Ledge (station 10024). In 1915 the summer was likewise of this same type in the deeps of the gulf, with 34 to 34.1 per mille in the eastern side and 33.5 per mille in the western at the 175-meter level; but in other summers the salinity of the deep strata is more nearly uniform over the basin, as in 1913, when the values at 175 meters were 33.8 to 33.9 per mille in the western and eastern sides alike.[2]

At depths greater than 200 meters the indraft through the Eastern Channel does not have as free access to the two branches of the basin as at higher levels Consequently, their bottom waters have proved considerably less saline (34.5 per mille) than their union to the southeast, or than the Eastern Channel (35 per mille). The bottoms of the deep bowl-like depressions in the offing of Cape Ann, in the one side of the gulf, and off the mouth of the Bay of Fundy in the other, thus bear much the same relationship to the still deeper bowl into which the Eastern Channel opens as the sink off Gloucester and the other isolated sinks in the inner parts of the gulf bear to its basin in general.

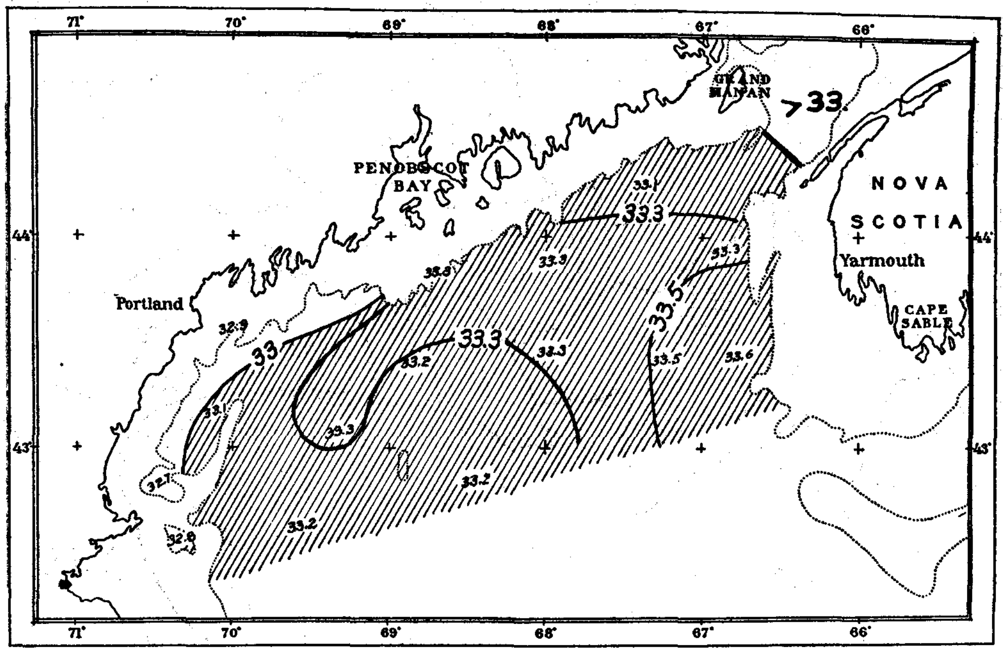

FIG. 148.—Salinity at a depth of 100 meters, August 5 to 20, 1913

At the 200-meter level (fig. 150) all the July and August determinations for the western bowl (stations 10007, 10088, 10254, and 10307) have ranged between 33.7 per mille and 34.11 per mille, showing that very little annual variation is to be expected there or regionally within its narrow confines. In the eastern bowl the

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[1] Only 5 stations were located in water as deep as 175 meters in 1912, and at only 3 of these can the 175-meter value be stated within ±0.1 per mille.

[2] No observations were taken in the southeastern part of the area in August of 1912, 1913, or 1915.

salinity has averaged higher, most of the determinations falling between 34 per mille and about 34.5 per mille, with the highest readings localized along the eastern and northern slope and the lowest (33.4 to 33.6 per mille) in its southwestern side (stations 10249, Aug. 13, 1914, and 10309, Sept. 1, 1915).

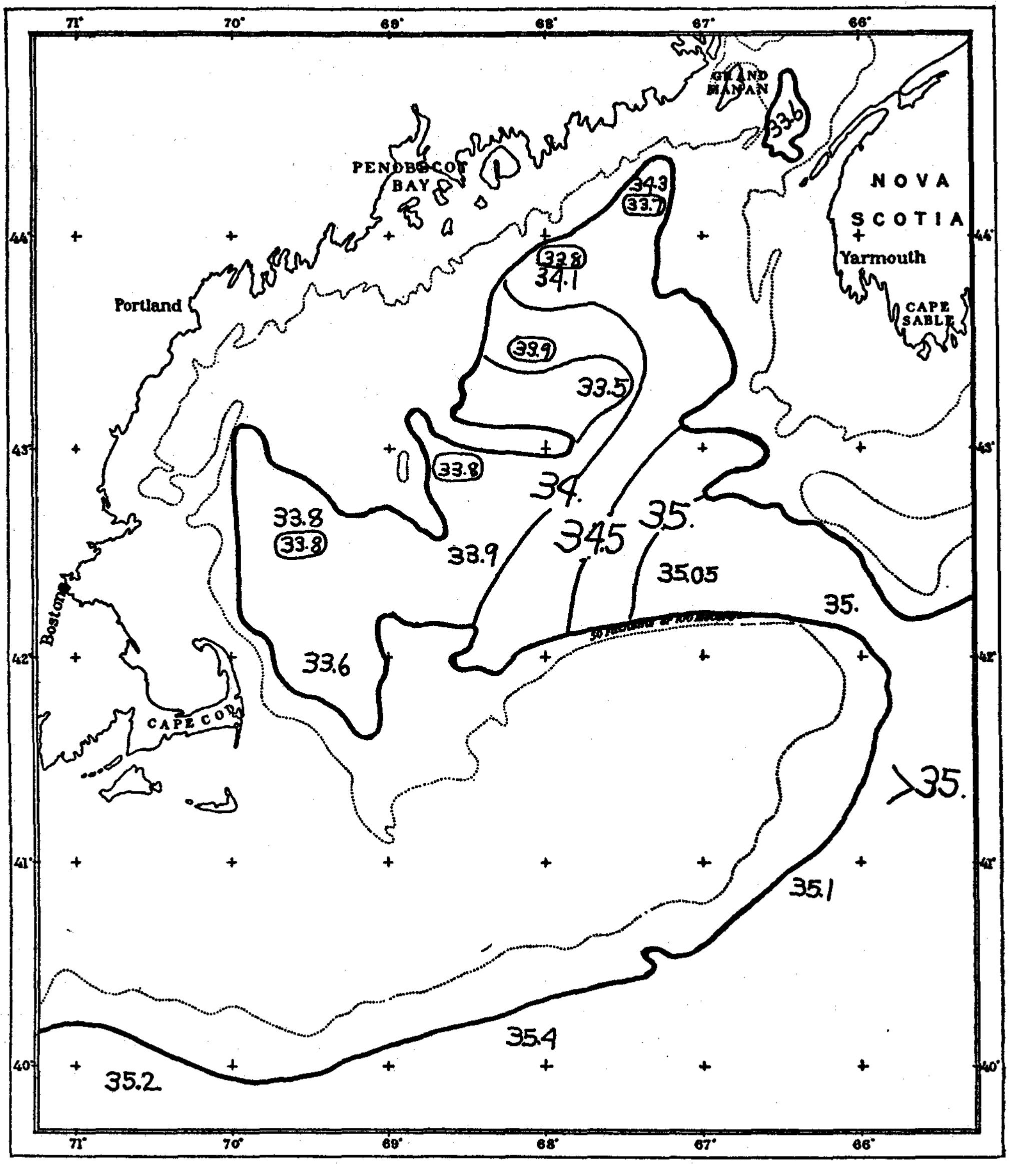

FIG. 149.—Salinity at a depth of 175 meters for August, 1913 (encircled figures), and for July 19 to August 26, 1914 (plain figures). Data for the Bay of Fundy from Craigie (1916a)

The midsummer charts, compared with the state of the gulf in June (p. 762), suggest an interesting seasonal progression, with the slope water of high salinity (34 per mille) spreading inward from the channel over the bottom, to occupy all the southeastern part of the gulf and northward to the northern slope. It is possible that in some years the inflow may continue actively until late in August; but the data for 1913, 1914, and 1915 make it more likely that the indraft usually slackens by the first of July, if not earlier, when a progressive tendency toward the regional equalization of salinity naturally ensues by various local circulatory movements of the water. It is also possible that slope water enters in much greater volume in some years than in others.

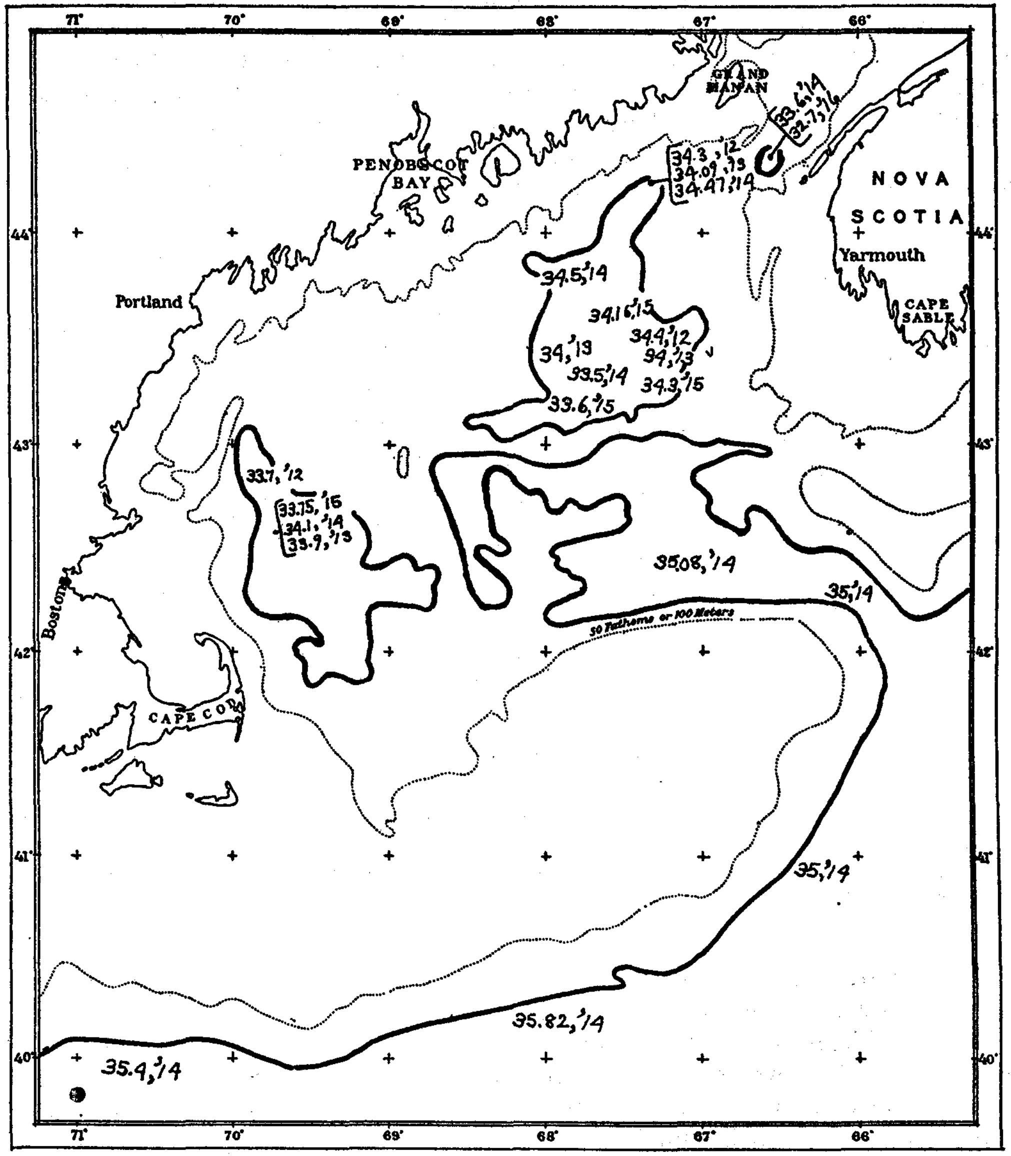

FIG. 150.—Salinity at a depth of 200 meters, July and August, 1912 to 1915

It seems, however, that these changes involve the Bay of Fundy to only a small degree at 100 meters or deeper, for in 1917 the salinity at that level changed from 32.4 per mille on July 4 to about 33 per mille on September 3 at a station off Grand Manan (Mavor, 1923, p. 375). Values differing little from this are evidently to be expected in the bay at this depth at the end of most summers, witness Craigie's (1916a) records of 33.3 to 32.4 per mille in 1914[3] and Mavor's (1923) of 32.6 to 33 per mille in 1919. However, sufficient water of high salinity flows into the bottom of the bay in late summer to maintain a more or less constant (though slight) differential between lower values along its northern side and higher values in its trough, with the water along its Nova Scotian slope intermediate in salinity at depths greater than 100 meters instead of most saline, as it is at the 40-meter level (p. 783).

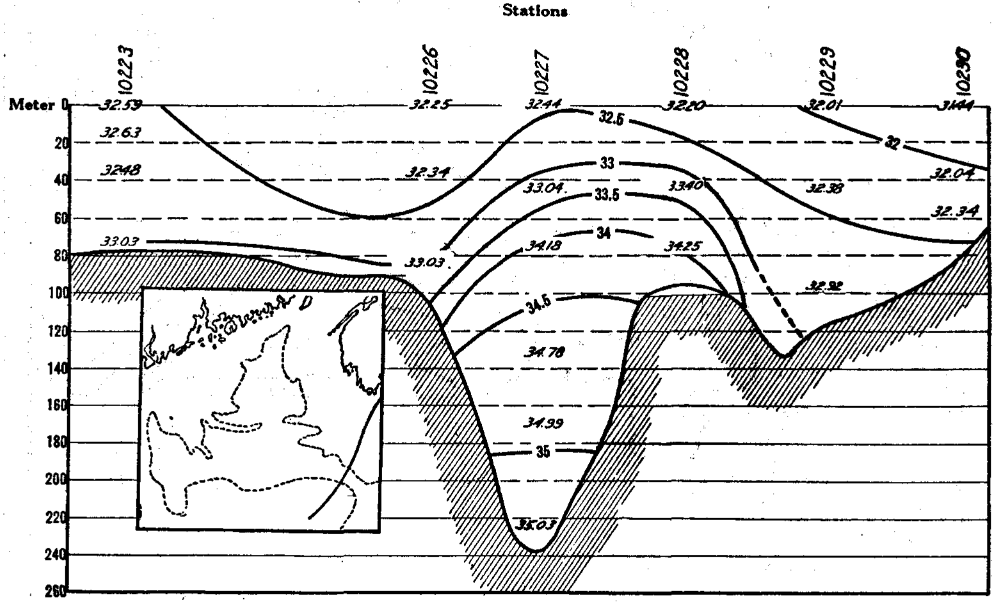

FIG. 151.—Salinity profile running from the eastern part of Georges Bank (stations 10223 and 10226) across the Eastern Channel (station 10227), Browns Bank (station 10228), and the Northern Channel (station 10229), to the offing of Cape Sable (station 10230), for July 23 to 25, 1914

PROFILES

The relationship that the slope water of high salinity in the Eastern Channel bears to the shallows on either hand, and especially to the overflow over Browns Bank, is most graphically illustrated on the July profile (fig. 151), as is the fact that the eastern edge of Browns was its extreme boundary in that direction (and always has been in our experience), where it gives place by abrupt transition to much less saline water in the Northern Channel, and so in toward the land near Cape Sable. The profile also corroborates the evidence of the charts to the effect that this water of high salinity was not overflowing at all on Georges Bank at the time. In fact, it is doubtful if it does so at any season, for we have found no evidence of such an event, either in spring or in summer.

Calculated from Craigie's hydrometer readings.

The course of the isohaline of 32.5 per mille over Georges Bank in this profile is also worth comment in connection with the northeastern to southwestern tongue of low salinity and low temperature recorded there at the surface (p. 770) as evidence of a counter movement out of the gulf, eddying clockwise around the eastern end of the bank (fig. 207). The confinement of the slope water between the banks is also illustrated by a summer chart of the 34 per mille water (fig. 152), as is its extent at that season compared with the spring (fig. 118).

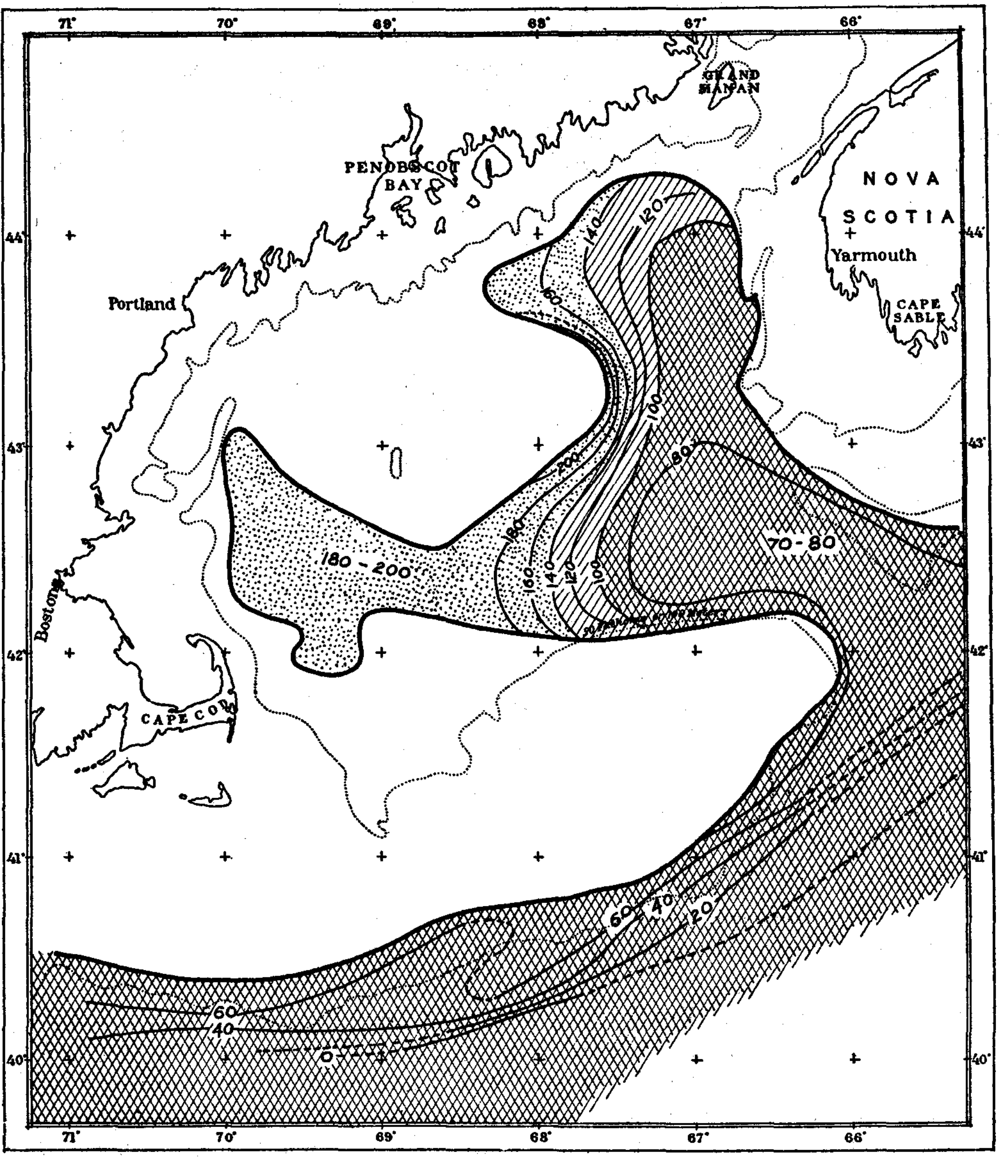

FIG. 152.—Depth below the surface of the isohalobath for 34 per mille, July to August, 1914

The constant tendency of the slope water to bank up against the eastern (Nova Scotian) slope of the gulf as it drifts inward over the bottom has been mentioned repeatedly in the preceding pages. The consequent concentration of the highest salinities (34 per mille) in the eastern side of the basin, reappearing from month to month on the charts for the deeper levels, is illustrated perhaps more clearly on a profile running from the center of the gulf toward Cape Sable for August, 1914 (fig. 153), than on any of the others, though corresponding profiles for August, 1913 (Bigelow, 1915, fig. 48), and for August-September, 1915 (fig. 154), show something of the sort. On August 12 and 13, 1913, for example, the isohaline for 33 per mille in profile revealed a very decided banking up in the mid-strata on the Nova Scotian slope off the mouth of the Bay of Fundy (Bigelow, 1915, fig. 53), although not of the deepest and most saline water. In 1914 this banking up involved the whole column of water right up to the surface at the time of our cruise. In this region of such active tidal circulation, however, sporadic vertical movements of this sort are to be expected; a profile run a few days earlier or a few days later might have agreed more closely in this respect with the profiles for 1913 and 1915.

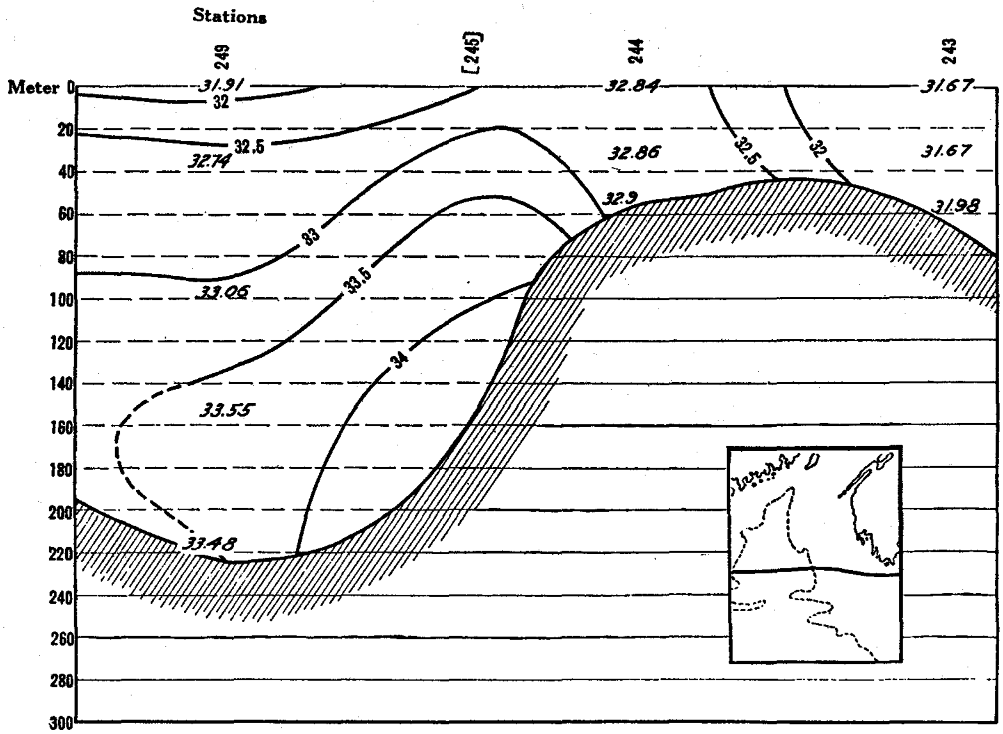

FIG. 153.—Salinity profile running eastward from the offing of Cape Sable (station 10243) toward the center of the Gulf of Maine (station 10249), for August 11 to 13, 1914

In 1913, 34 per mille water occupied the whole breadth of the eastern arm of the basin. In 1913 and 1914, however, slightly lower salinities prevailed in its western side, a difference reflecting a corresponding difference in the circulation of water over the bottom for the preceding weeks.

The eastern ends of the summer profiles along this general line confirm the evidence of the charts to the effect that the flow of Nova Scotian water past Cape Sable nearly or quite ceases before July, by the extremely abrupt transition in salinity between the stations just to the west of the cape (32.4 to 32.8 per mille) and those in its offing or just to the east of it (<32 per mille).

The western end of any summer profile along this line, whether for 1913 or for 1915 (fig. 154), is interesting chiefly for its demonstration that off Massachusetts Bay water less saline than about 32.5 per mille occupies a cross section hardly less extensive than in May (fig. 126), though with the isohaline for that value pointing to some tendency for the fresher water to expand, seaward, over the salter. A relationship of this same sort also appears, as might be expected, on other profiles running out normal to the coast line, at several locations between Cape Ann and the Bay of Fundy, for the summers of 1912 and 1913 (Bigelow, 1914, figs. 30 to 32, and Bigelow, 1915, figs. 49 to 51).

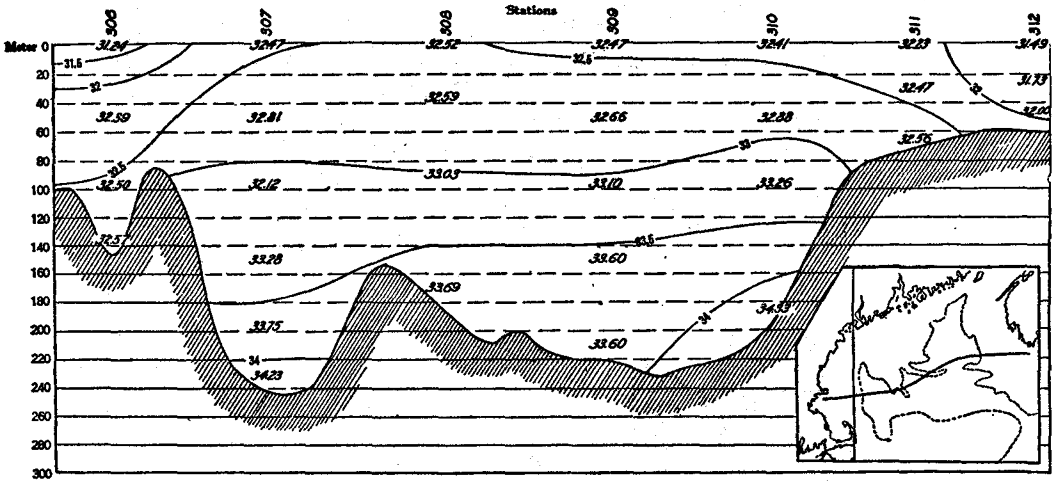

FIG. 154.—Salinity profile running eastward across the gulf from the mouth of Massachusetts Bay (station 10306) to the offing of Cape Sable (station 10312), August 31 to September 2, 1915

The summer profiles also supplement the charts for the 100-meter level in making clear the isolation of the sink off Gloucester (typical of all such sinks) by its barrier rim, resulting in the vertical homogeneity of salinity below the level of the latter, with a considerably lower value at the bottom of the sink than at an equal depth in the basin outside, which is characteristic of this situation.

The summer state of the water in the bowl inside Stellwagen Bank and in the deep channels that give entrance to it on the north and south is developed by profiles crossing the mouth of Massachusetts Bay for August 31, 1912 (Bigelow, 1914, fig. 33), July 19, 1916 (fig. 155), and August 22, 1922 (fig. 140). In the summers of 1916 and 1922 the saline bottom water (>32 per mille) of this bowl was continuous with the still higher salinities of the basin of the gulf outside via the floor of the channel next Cape Ann, but was entirely cut off to the southward by Stellwagen Bank. Consequently, any bottom drift that may have been taking place into the bay at the time, or shortly previous, must have followed the northern route.

In 1922, also, the upper 50 meters was least saline in the northern side of the bay, as might be expected if the general anticlockwise eddy enters it. This is probably the usual state at the end of the summer, also, unless temporarily interrupted by the offshore winds, when temporary upwellings may be responsible for surface salinities higher in the northern side of the bay than in the southern side (so confusing the picture), as appears on the July profile for 1916 (fig. 155).

Our own cruises do not afford summer profiles for the Bay of Fundy; but Mavor (1923) gives several such for August, 1919, cross-cutting the bay at intervals, all of which show the upper strata of water on the whole salter in the southern (Nova Scotian) than in the northern (New Brunswick) side. This distribution, as Mavor has brought out, corresponds to a tendency for the outpouring discharge of fresh water from the St. John River to spread southwestward along New Brunswick, while the salter water (32 to 32.5 per mille) tends to bank up against Nova Scotia, giving a marked obliquity to the isohalines. In the bottom of the trough of the bay Mavor's profiles show the saltest and coldest water (33 to 33.1 per mille) as a longitudinal ridge, which he explains (Mavor, 1923, p. 364) as due to a rotation of the deeper water around this locality as a center. Concentration of the lowest salinities in the northern side also appears in the densities on profiles of the lower part of the bay for August, 1914 (Craigie, 1916a), proving this the usual summer state.

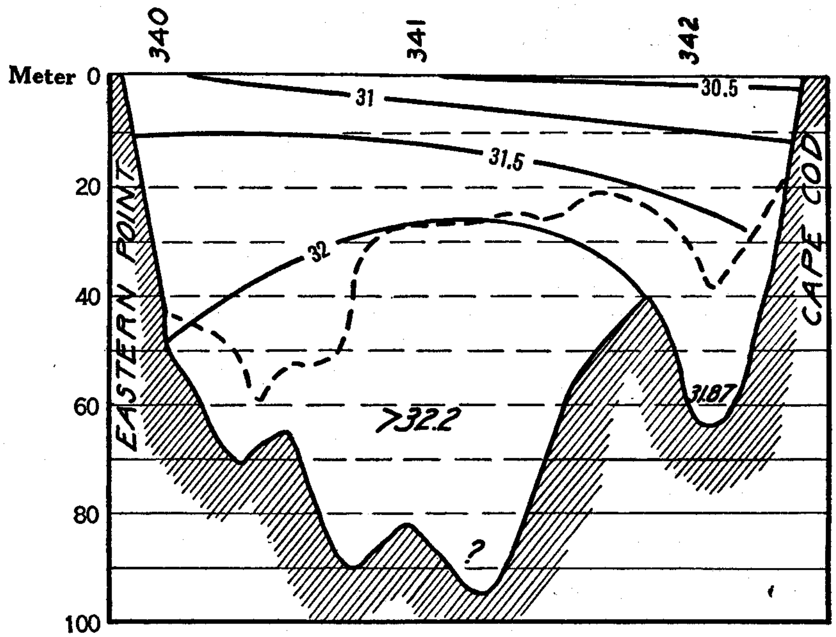

FIG. 155.—Salinity profile crossing Massachusetts Bay from the eastern point, Gloucester to Cape Cod, just inside Stellwagen Bank for, July 19, 1916. The broken curve gives the contour of the bank (stations 10340 to 10342)

The characteristic contrast, below the surface, between the high salinity of the Atlantic basin and the much less saline water of the continental slope and shelf is brought out graphically for the summer months by the profiles (figs. 156 to 158) for 1914. Whether in July (figs. 156, 157) or in August (fig. 158), the successive isohalines show a sudden transition from the one to the other (most abrupt at this shoaler levels) and parallel to the edge of the continent. It is especially suggestive that while considerable overflows of water more saline than 33 per mille appear on the profiles in two regions—one from the Eastern Channel across Browns Bank, as just described (p. 788), and the other in the offing of Nantucket Shoals—neither profile (nor the chart for 200 meters, fig. 150) suggests any tendency for this most saline water to enter the Eastern Channel. On the contrary, the isohalines for the highest values at each level cross the latter, leaving the oceanic triangle occupied by the intermediate salinities of the slope water (33 to 35 per mille).

As to the date when bottom water of high salinity may be expected to drift in over the edge of the continent toward Nantucket Shoals, I can only point out that in 1913 water of 33 to 33.5 per mille and upwards in salinity was encountered at 40 meters over the outer edge of that sector of the shelf as early as July 10 (stations 10060 to 10062). In 1914 water of this high salinity had encroached on the southwestern part of Georges Bank by July 19 and had reached the 40-meter contour off Nantucket Shoals some time prior to the last week in August (fig. 145); but in 1916, a backward year (p. 772), the bottom water over this part of the shelf was only 32.5 to 33 per mille on July 19 to 25 (stations 10354 to 10355, fig. 159)—i. e., about 1 per mille less saline than at about the same season of 1913 or of 1914, corresponding almost exactly to the readings obtained there in May, 1920.

Water more saline than 35 per mille may be expected to wash the slope at the 100-meter level right across the mouth of the gulf at some time during the summer, and perhaps continuously throughout the summer during some years, for the Canadian Fisheries Expedition had 35.35 per mille at 100 meters on the slope of the La Have Bank in July, 1915 (Bjerkan, 1919; *Acadia* station 41), where the 100-meter salinity on July 28, 1914, was only 34.16 per mille (station 10233; both readings taken over the 450-meter contour line).

Only on one occasion have our lines reached water of full oceanic salinity (36 per mille)—namely, abreast the western end of Georges Bank on July 21, 1914 (p. 780, figs. 145 and 156). Failure to find water as saline as this at our outermost stations anywhere else between the offings of Chesapeake Bay and Cape Sable on any other cruise, or off Nova Scotia, suggests that this pure "Gulf Stream water" may be expected to approach the edge of the continent more closely thereabouts, as it moves northward in summer, than either to the west or to the east.

We have yet to learn whether oceanic water approaches so close to the edge of the continent every summer as it did in 1914. In 1913 and 1916 (the one an early and the other a late season in the sea) it certainly did not do so until well into the summer, if at all. We may assume, therefore, that the situation pictured on the July profile for 1914 (fig. 156) is most likely to be reproduced in August, taking one summer with another.

Although this highly saline water probably approaches within a few miles of the 200-meter contour at about this longitude (68° to 70°) by the end of every August, it has never been found actually encroaching on the continental shelf abreast of the Gulf of Maine or anywhere else along the North American littoral north of Chesapeake Bay at any season. Bjerkan's (1919) record of 35.9 per mille at 50 meters at the *Acadia* station 44 miles off La Have Bank on July 22, 1915, combines with our own data for 1914 (fig. 145) to show the isohalines for 35.5 and 36 per mille departing farther and farther from the continental edge, passing eastward from Georges Bank, and so leaving a less saline wedge (34.5 to 35.5 per mille) some 60 miles wide off the mouth of the Eastern Channel. This fact is worth emphasis as one of the numerous bits of evidence that the indraft that takes place into the eastern side of the gulf, via this channel, is constantly of the so-called "slope" origin (p. 842), thus accounting for the rarity of tropical planktonic animals and plants within the gulf (Bigelow, 1925).

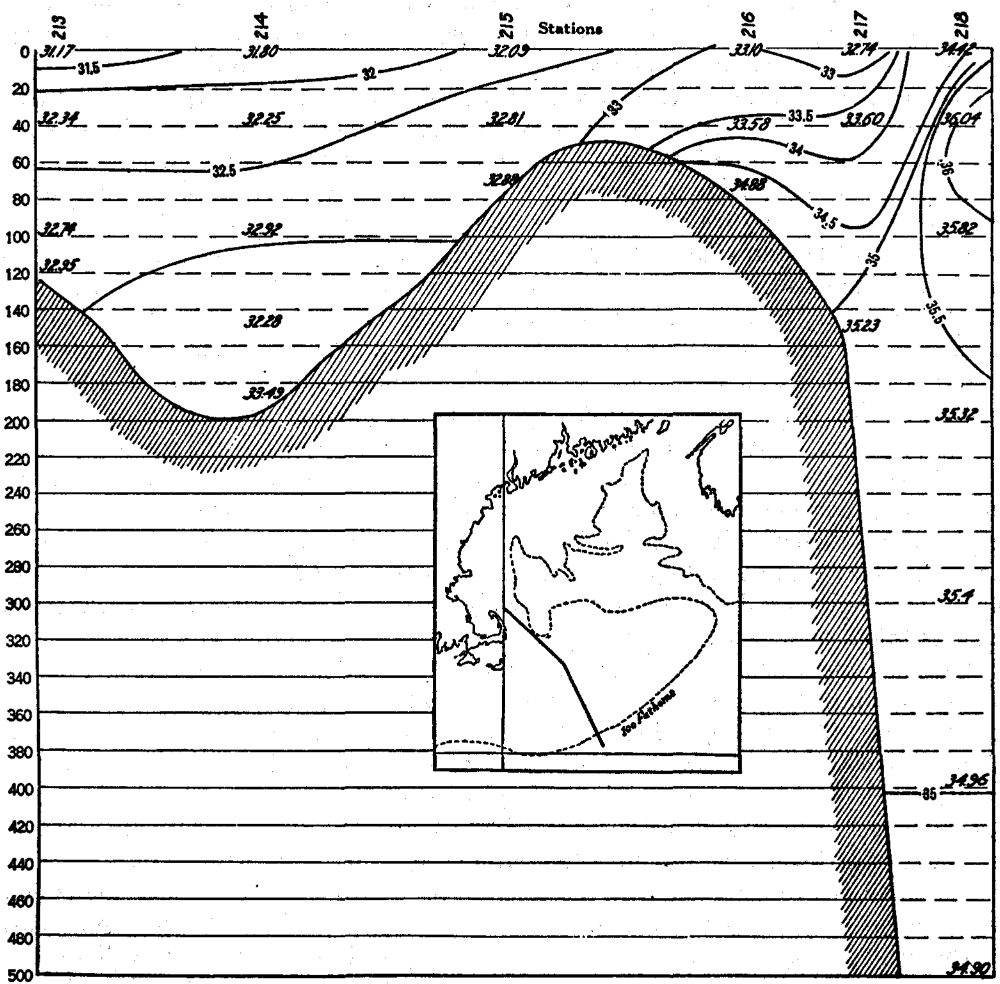

FIG. 156.—Salinity profil running from a station (10213) off northern Cape Cod, southward across the western end of Georges Bank (stations 10215 and 10217), to the continental slope (station 10218), July 19 to 21, 1914

When the transition in salinity is as abrupt along the edge of Georges Bank as it was in July, 1914 (fig. 156), to speak of a salinity "wall" is excusable exaggeration. At such times the following waters may be named, successively, along any profile crossing Georges Bank from north to south:

First, in the basin to the north of the bank is the Gulf of Maine complex, ranging in salinity hereabouts from about 32 per mille at the surface to about 33.5 per mille at a depth of 200 meters and close to 34 per mille in the still deeper trough of the basin. The northern part of the bank is washed by the typical "banks" water, with a mean salinity of 32.5 to 33 per mille, which in the shoaler parts is kept nearly uniform, vertically, by tidal stirring. Over the seaward slope the zone of transition to the much more saline water is condensed into so narrow a zone that the successive isohalines become nearly perpendicular on the distorted scale adopted for the profiles, their precise degree of obliquity depending, of course, on the proximity of the oceanic water to the south. Finally, at the offshore end true oceanic or

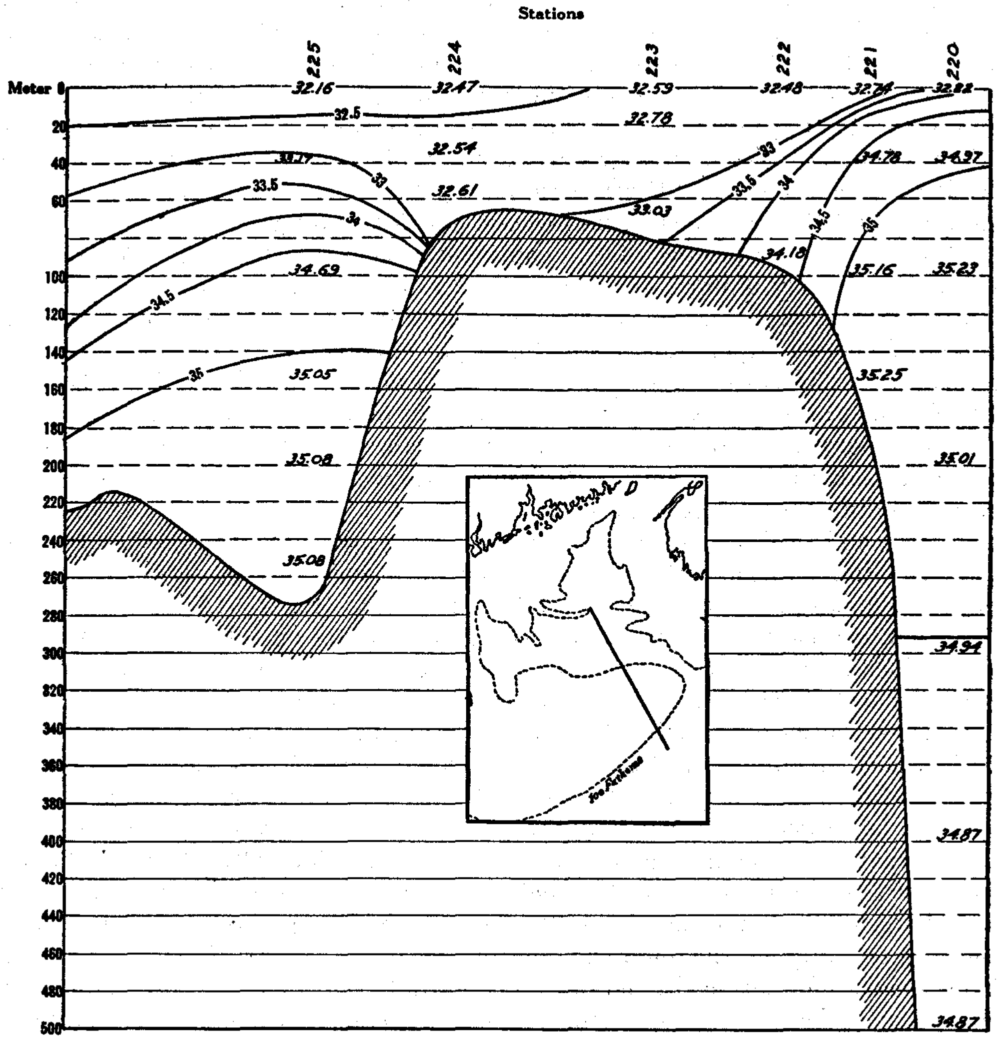

FIG. 157.—Salinity profile running from the southeastern part of the gulf (station 10225), southward across the eastern end of Georges Bank (stations 10221 to 10224) to the continental slope (station 10220), July, 1914

"Gulf Stream" water more saline than 36 per mille will be met if the profile runs out far enough.

Farther east (fig. 157) a rather different picture results from the homogeneous state of the water maintained on the bank by active tidal stirring, as described above (p. 770); but the contrast between the comparatively low salinity there and the much higher values on the continental slope to the south, on the one hand, as well as in the basin of the gulf to the north, on the other (34 per mille), affords a graphic illustration of the extent to which the contour of the bottom controls the relationship of water masses that differ in salinity because of different origins. Note also the abrupt transition from the thick layer of 35 per mille water in the bottom of the basin to the very much lower salinity (about 32.2 per mille) at the surface on this profile, reflecting the considerable difference in density that exists in summer between the slope water and the surface stratum beneath which this intrudes.

All three summer profiles of the continental shelf for 1914 (figs. 156, 157, and 158) show extremely uniform salinities of 35.2 to 35.4 per mille bathing the bottom at about 100 to 200 meters depth all along the slope abreast the gulf; and as the Canadian Fisheries Expedition also had 35.4 per mille at 200 meters just outside the continental edge in the offing of Shelburne, Nova Scotia, on July 22, 1916 (Bjerkan, 1919; *Acadia* station 41), this may be taken as normal for the summer.

In February and March, the reader will recall, only the western sector of this zone was as salt as this; in July, 1916, the values were slightly below 35 per mille (fig. 159)—differences that apparently reflect the normal seasonal succession in the inshore and offshore movements of oceanic water. On this assumption the maximum salinity of the eastern sector of the warm zone for the year is not far from 35.5 per mille, and the minimum certainly is as low as 34.5 to 34.7 per mille.

At depths greater than 400 meters the bottom water on this sector of the continental slope is always close to 34.9 to 35 per mille in salinity, perhaps never varying more than 0.2 per mille from this mean value at any time of year.

Lower salinities off Marthas Vineyard in July, 1916 (fig. 159), than in August, 1914 (fig. 158), no doubt reflect the normal seasonal succession in this part of the sea, suggesting that values less than 32 per mille will seldom be recorded on this line after July, and that water more saline than 33 per mille may be expected to move inshore over the bottom during that month and August (p. 793). The fact that the water over the median sector of the shelf was nearly homogeneous in salinity, surface to bottom, at that time (fig. 158), contrasting with pronounced stratification closer into the land, on the one hand, and farther out at sea, on the other, is unmistakable evidence of active circulation. The abrupt transition from low salinities to high ones over the edge of the continent, made evident on the profile by the isohalines for 34, 34.5, and 35 per mille, also marks this as the zone of contact between two distinct masses of water at the time (p. 795). The rather unusual vertical distribution of salinity about one-third the way out from the land where the mid stratum was less saline than either the surface above it or the bottom, has been commented on (p. 779).

These two profiles (figs. 158 and 159) are also of interest from a more general viewpoint as illustrations of the general increase in salinity from the land seaward, which is characteristic of the whole continental shelf between Cape Cod and Chesapeake Bay.

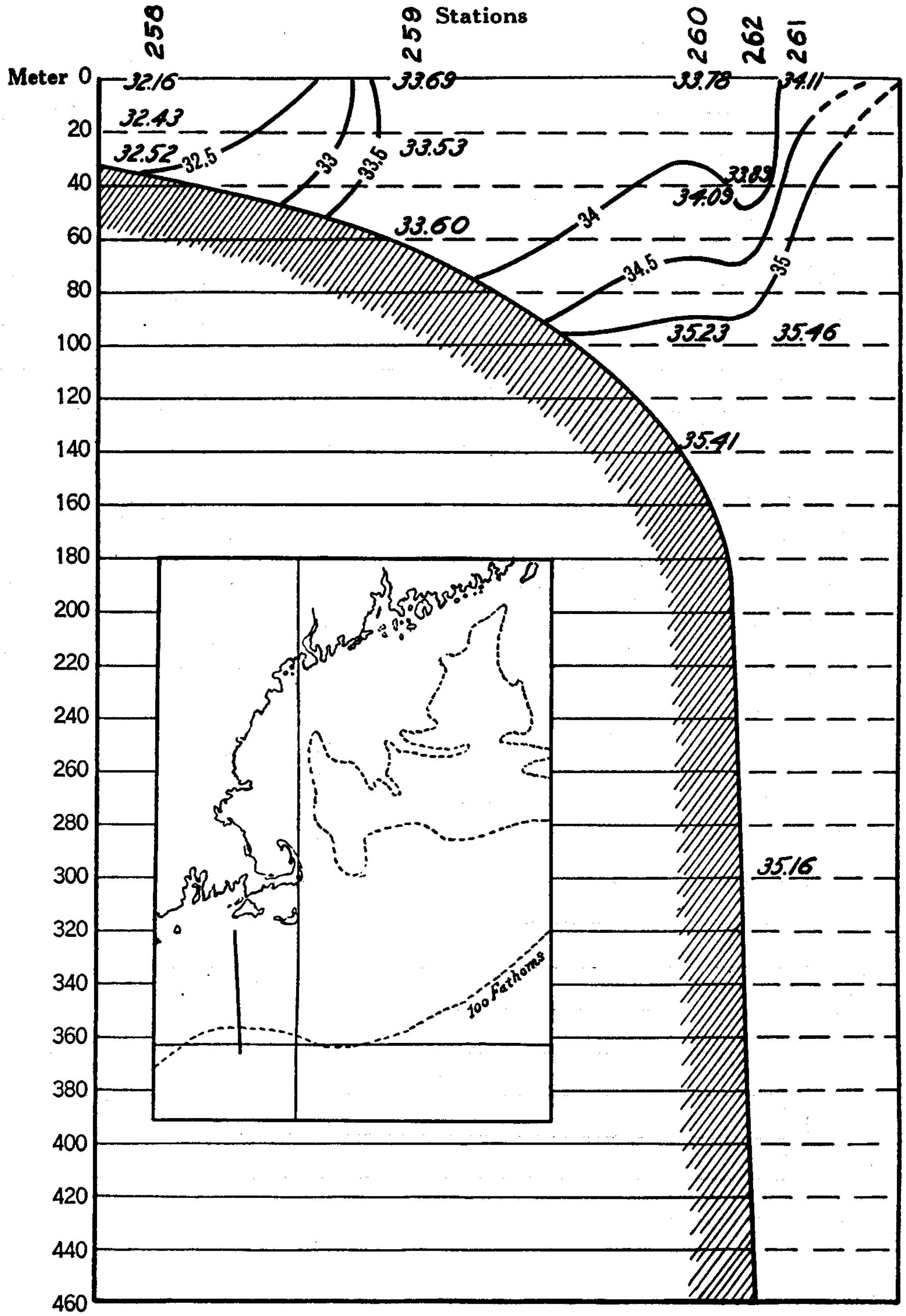

FIG. 158.—Salinity profile running southward from the offing of Marthas Vineyard (station 10258) to the continental slope (station 10261) for August 25 and 26, 1914

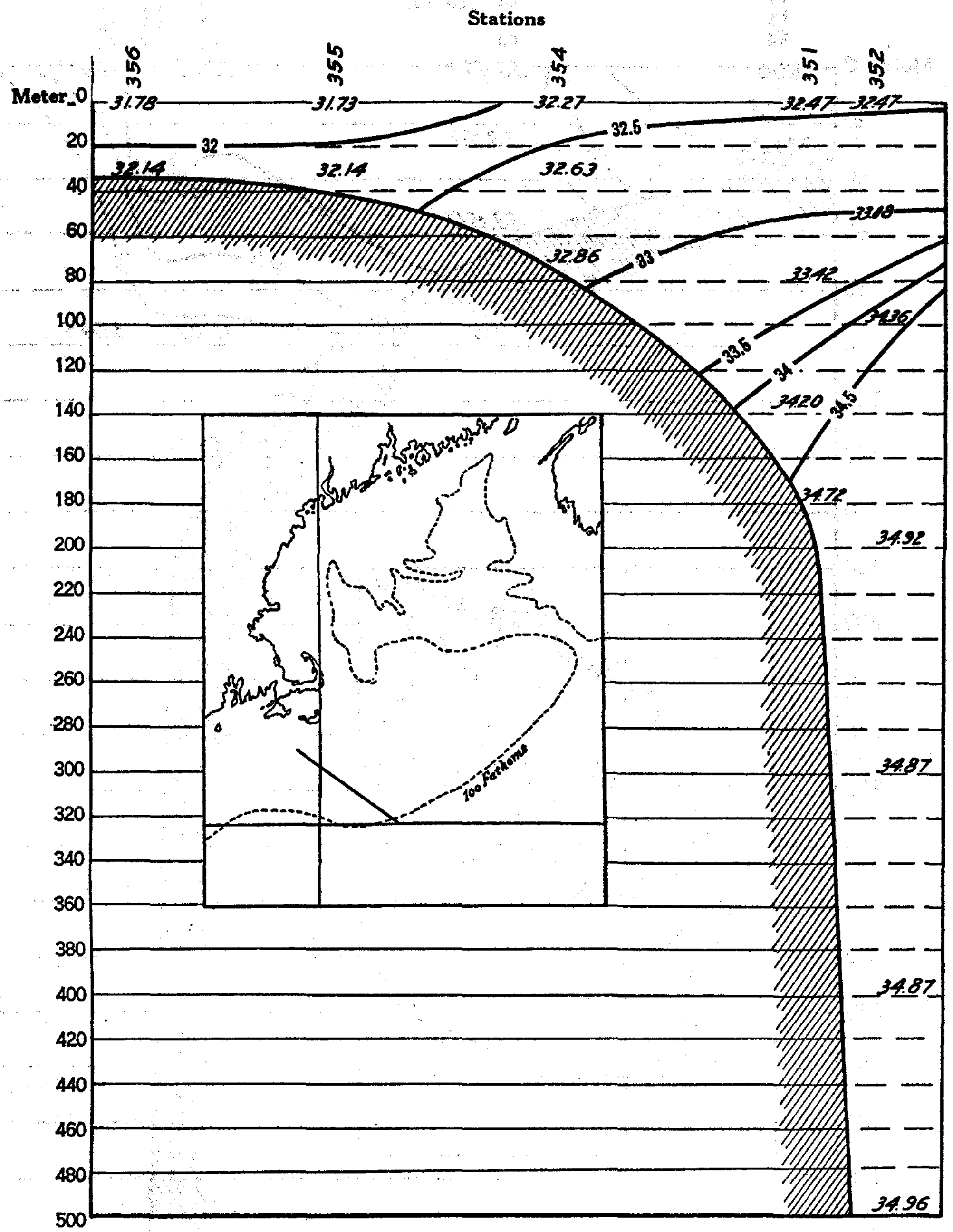

FIG. 159.—Salinity profile running southeasterly from the offing of Marthas Vineyard (station 10356) to the continental slope (station 10352) for July 24 to 26, 1916

SALINITY IN AUTUMN AND EARLY WINTER

Observations taken through September and October of 1915, in early November of 1916, and at the end of that month in 1912 afford a general picture of the salinity of the northern and western parts of the gulf at that season. Vachon (1918) and Mavor (1923) also give autumnal data for 1916, 1917, and 1919 for various localities in the Bay of Fundy region.

In 1915 pairs of successive stations were occupied at intervals, expressly to show the seasonal changes, if any; and when the salinities for these are plotted an increase of 0.6 to 1.1 per mille is shown at the surface all along the coastwise belt east of Cape Elizabeth from July and August to October—an increase of about 0.5 to 0.9 per mille at the 50 to 60 meter level. At the same time, however, the vertical range of salinity decreased somewhat off Mount Desert (fig. 107) and off Machias, a change foreshadowing the vertical equalization of the water that takes place in winter (p. 801).

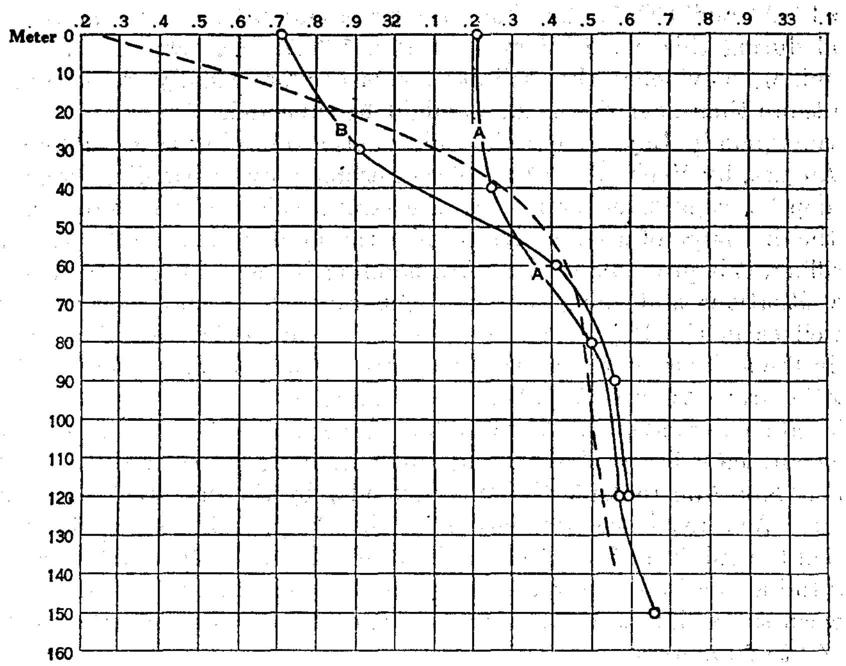

FIG. 160.—Vertical distribution of salinity off Gloucestor, August 31, 1915 (station 10306, dotted curve), October 1, 1915 (A, station 10324), and October 31, 1916 (B, station 10399)

A pair of stations for August 31 and October 1, 1915 (stations 10306 and 10324), show a corresponding increase of nearly 1 per mille in the salinity of the upper 40 meters of water over the sink off Cape Ann at the mouth of Massachusetts Bay (fig. 160), though very little change took place at depths greater than 50 meters meantime, proving that the surrounding rim isolates its deeper strata of this bowl effectively in autumn as it does earlier in the season.

The superficial stratum off the mouth of Massachusetts Bay also seems to have experienced some increase of salinity during the early autumn of 1916, the surface value being about 0.5 per mille higher at the station in question (10399) on October

31 than at a locality a few miles to the south on August 29 (station 10398), with almost precisely the same values at depths greater than 50 meters as in August and October, 1915. Increasing salinity in the upper strata, contrasted with constancy in the deep water, is thus a regular accompaniment of advancing autumn in this locality.

Tidal currents being comparatively weak here, autumnal salting at the mouth of Massachusetts Bay reflects some widespread change of the same sort, not simply vertical mixing *in situ*. The extent to which the inner waters of the bay share in this alteration during the early autumn is therefore interesting. Unfortunately, this can not be stated, for want of data at successive dates throughout any given season; but the fact that the surface of the northern side of the bay had virtually the same salinity on October 26 and 27, 1915 (stations 10338 and 10339), as a month earlier (stations 10320 and 10321), but had become about 0.5 per mille more saline near Cape Cod during this same interval (station 10322, 31.4 per mille; station 10337, 31.9 per mille), is evidence that salinity increases more rapidly at the mouth of the bay in autumn than near the head, as might be expected.

Passamaquoddy Bay, across the gulf, is also somewhat more saline in October than in August, by Vachon's (1918) observations, notwithstanding irregularities in the mid depths, caused, no doubt, by the strong tides. As Passamaquoddy Bay receives the discharge of a large river, while the land drainage into Massachusetts Bay is trifling, it is probable that a corresponding increase in salinity takes place in estuarine situations and along the shore generally all around the coast line of the gulf as well as in the Bay of Fundy, where Mavor (1923) records a considerable increase in the salinity of the upper 80 meters of water between Grand Manan and Nova Scotia[4] from August 25, 1916, to November 6.

Such data as are available for October make it likely that this general salting brings the surface salinity above 32 per mille all along the coastal belt to the north and east of Cape Ann (outside the outer islands) by the first week of the month in most years. As a result the area less saline than 32 per mille which skirts the whole coast line of the gulf from Cape Cod to the Bay of Fundy in July and August (p. 769), contracts to include Massachusetts Bay alone by mid autumn. A similar relationship between the salinities of late summer and of mid autumn prevails down to a depth of 40 to 50 meters.

Some increase in the salinity of the upper stratum of water was naturally to be expected along this sector of the coast line in autumn as the effects of the vernal discharges from the rivers are gradually dissipated. If this process of mixture is accompanied by an active indraft of highly saline water into the bottom of the gulf the increase will involve the whole column right down to the deepest stratum of the basin; otherwise the intermingling of comparatively low salinities from above with higher salinities from below must result in lowering the salinity of the deeper strata while raising that of the shoaler. The vertical distribution of salinity is therefore an index to the strength of the bottom drift in autumn.

Unfortunately, no deep stations were occupied during the autumn of 1915; but on November 1, 1916, observations taken in the basin off Cape Ann (station 10401) yielded decidedly lower salinities in the deepest stratum than we have ever found

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[4] *Prince* station 3 (Mavor, 1923, p. 374)

there in the summer in any year. True, the seasonal succession is not altogether clarified thereby, because of the certainty that annual differences are sometimes wider than the seasonal differences; 1916 may have been a fresh autumn, while the summers of 1913 and 1915 were certainly more saline than those of 1912 or 1914. At least there is nothing in this record to suggest an active inward pulse of slope water during the early autumn, but rather the reverse; and the relationship between the salinities for that date, on the one hand, and the curves for July 17, 1912, and August 22, 1914, on the other (stations 10007 and 10254), is what might be expected in the normal seasonal succession, with vertical stirring by tidal currents, winds, and waves becoming increasingly more effective through the autumn, when cooling at the surface decreases the vertical stability of the water.

We have no data for salinity on the offshore banks—Georges or Browns—for October or later in the autumn; but profiles of the continental shelf in the offing of Marthas Vineyard and a few miles farther west, run by the *Grampus* during the third week of October, 1915 (stations 10331 to 10334), and on November 10 and 11, 1916 (fig. 162), show that if slope water had worked in over this sector of the shelf along this line during the preceding summers it had moved out again from the edge of the continent by mid autumn, leaving values lower than 34 per mille out to the 120-meter contour. It is likely, therefore, that such encroachments of high salinity over the outer edge of the continental shelf off southern New England as are described above (p. 796) are strictly summer events. For water as saline as 34 per mille to continue on this part of the shelf after the end of September would, it seems, be an unusual event.

If the inshore ends of these two profiles, in combination, represent the usual October-November state, and if conditions prevailing there in August, 1914 (p. 796, fig. 158), are equally representative of that season, the coastwise water less saline than 32.5 per mille spreads out from the land, seaward, during the autumn, until the isohaline for this value includes the bottom out to the 40 to 60 meter contour and the surface halfway acoss the shelf.[5] The relationship between this November profile and the profile off New York for that August affords further evidence of similar import, as remarked elsewhere (Bigelow, 1922, p. 125, figs. 23 and 38).

The most interesting alteration that takes place later in the autumn is that the vertical range of salinity in the upper 100 meters, like that of temperature, decreases as the water loses stability and as tides and winds stir it more and more actively.

Observations on the salinity of the gulf for the last half of November and first half of December have been confined to the bowl at the mouth of Massachusetts Bay off Gloucester in 1912 (Bigelow, 1914a, p. 416), and to the deep trough of the Bay of Fundy, between Grand Manan and Nova Scotia, in 1916 and 1917 (Mavor, 1923, p. 375).

At the first of these localities and years salinity had become virtually homogeneous at about 32.5 per mille from the surface down to a depth of about 50 meters by November 20, increasing slightly with increasing depth to 32.66 per mille at bottom in 62 meters (fig. 111). However, the fact that virtually no alteration of salinity had taken place at the bottom there since the preceding August (stations 10045

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[5] On the August profile (fig. 158) water less saline than 32.5 per mille did not touch the bottom at all at depths greater than 20 meters.

and 10046), though that of the surface had increased from 31.67 to 31.92 per mille to 32.57 per mille during the interval, is proof that the autumnal progression also reflected an indraft of more saline water over the rim.

Some salting of the whole column of water is to be expected, therefore, at the mouth of Massachusetts Bay during the late autum, besides the increase at the surface that stirring by tidal currents would, of itself, effect at this season. Although this alteration was not continuous in 1912, when salinity was almost precisely the same on December 4 as it had been on November 20 at the station in question,[6] it raised the salinity of the entire column (now homogeneous, surface to bottom) to about 32.75 per mille by the 23d of that month.

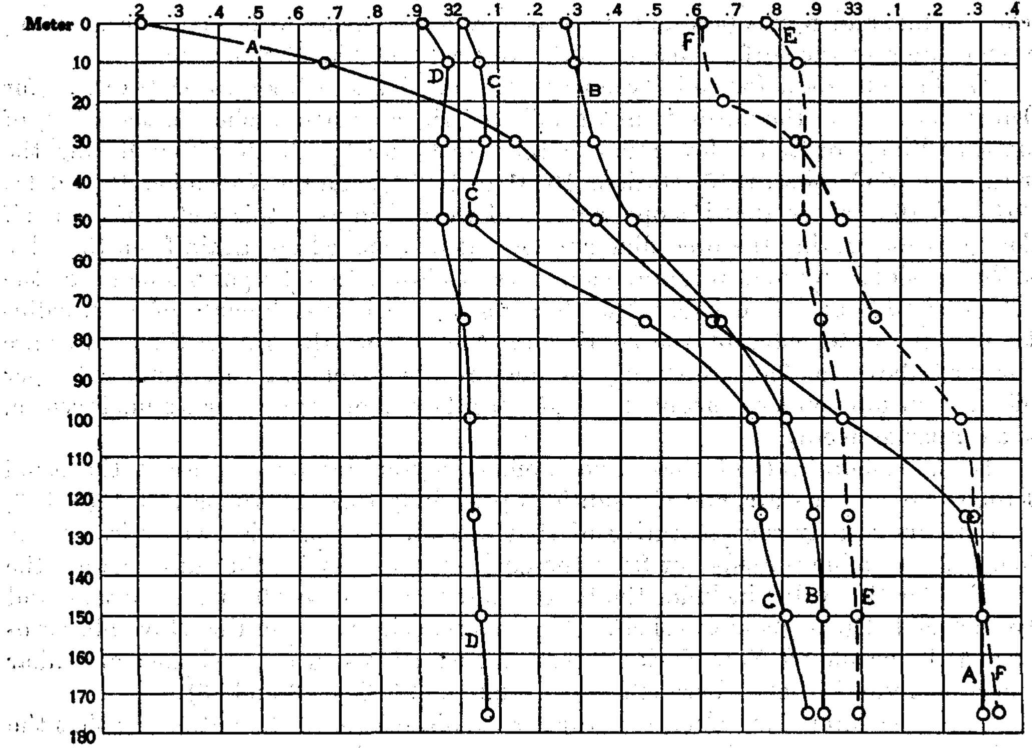

FIG. 161.—Vertical distribution of salinity in the Bay of Fundy between Grand Manan and Nova Scotia, in various months, from Mavor's table (Mavor, 1923, p. 375, *Prince* station 3). A, July 31, 1917; B, October 2, 1917; C, December 5, 1917; D, January 19, 1918; E, December 2, 1916; F, January 3, 1917

Mavor (1923) also records a considerable increase in the salinity of the upper strata of the Bay of Fundy from October 4, 1916, through November, although the bottom water continued virtually unchanged throughout that autumn. The vertical distribution for October 4 of that year[7] is especially interesting, the salinity being highest at 50 meters, with less saline water below it as well as above, and with a very abrupt increase near the bottom. A distribution of this sort, decidedly unusual

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[6] 32.56 per mille at the surface and at 46 meters; 32.61 per mille near bottom in 70 meters depth.

[7] 10 meters, 31.9 per mille; 50 meters, 32.6 per mille; 75 meters, 32.4 mille; 150 meters, 32.5 per mille; and 175 meters, 33 per mille.

in the Gulf of Maine region, suggests indrafts from the basin offshore at two levels—one centering at about 50 meters and the other over the bottom.

In 1917 the autumnal progression of salinity in the Bay of Fundy was of the reverse order (fig. 161), Mavor's (1923) records showing a decrease of about 1.2 per mille at all depths from October to December, as follows:[8]

Depth, meters	Oct. 2	Dec. 5	Depth, meters	Oct. 2	Dec. 5
Surface	32.27	32.00	100	32.81	32.72
50	32.43	32.03	175	32.90	32.86

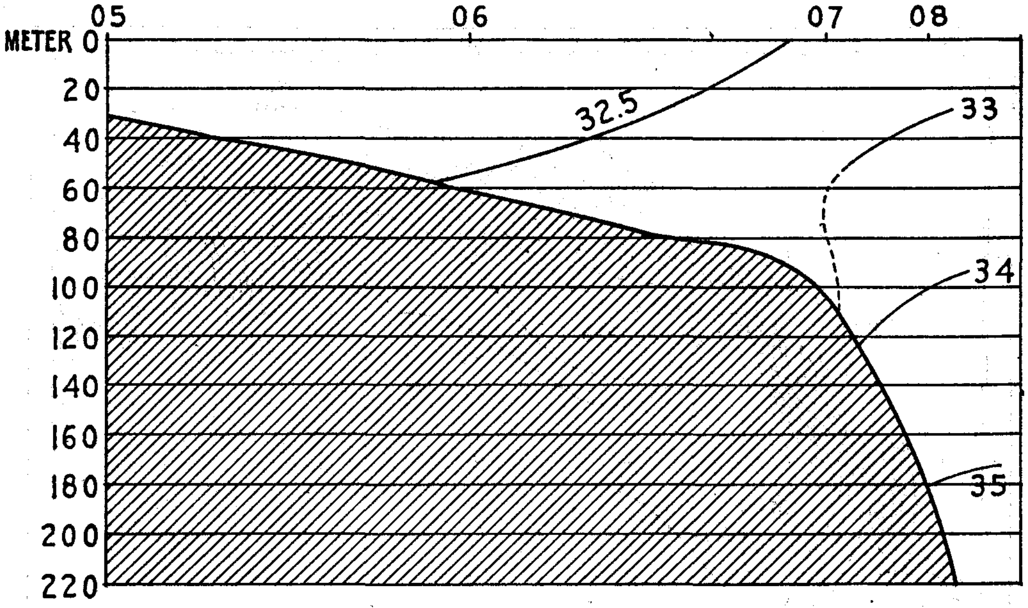

FIG. 162.—Salinity profile crossing the continental shelf off Marthas Vineyard, November 10 and 11, 1916. (From Bigelow, 1922, fig. 38)

It is obvious that with salinity increasing in the one year of record, decreasing in the next, neither an increase nor a decrease can be named as normal for the Bay of Fundy in late autumn. Freshening is probably to be expected there in years when the autumnal rains are heavy and the discharges from the St. John and from the other rivers tributary to the bay are correspondingly great, especially if the indraft over the bottom (which varies from year to year) is less active than usual. On the other hand, salting will follow after summers and autumns with light rainfall or with more than the usual contribution of saline bottom water. This explanation is partly corrobated by the fact that the year's precipation showed a deficiency of 11.45 inches from the mean at Eastport in 1916 (when the salinity of the bay rose in autumn), with every month from August to November falling low.

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[8] Condensed from Mavor (1923, p. 375).

SALINITY IN MIDWINTER

The general oceanographic survey of the inner part of the gulf carried out by the *Halcyon* during the last days of December and first half of January, 1920–21, affords our only picture of the salinity of the offshore waters for that season.

These midwinter observations prove interesting from several view points. In the first place, when added to the winter records for Massachusetts Bay and for the Bay of Fundy for other years they show that little alteration takes place in salinity from autumn to midwinter, evidence that this season sees no extensive indraft of the saline slope water over the bottom. The regional distribution of salinity in the upper 100 meters gives evidence to this same effect, for this was highest near shore in the western side of the gulf as in May instead of in the eastern, as is the rule at other times of year. This distribution appears most clearly on the surface projection (fig. 163), with 32.7 per mille off Cape Ann but only 32.5 per mille in the Nova Scotian side of the basin; likewise at 40 meters and at 100 meters, where these same localities were the most saline. These, in fact, were the only stations where the 100-meter salinity was then higher than 33 per mille, so that this isohaline paralleled the northern and western slopes of the gulf at this level.

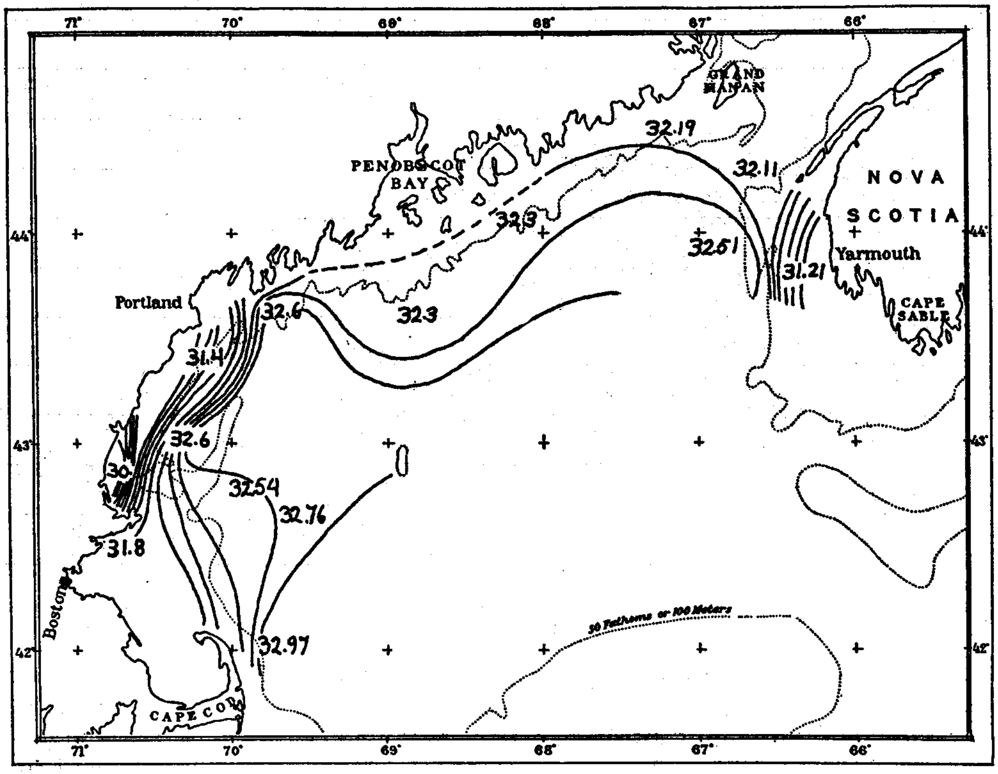

FIG. 163.—Salinity at the surface, December 29 1920, to January 9, 1921. Contours for every 0.2 per mille

The bottom water of the two sides of the basin at 200 meters and deeper then proved almost precisely alike in the two sides of the basin (about 33.9 per mille off

Cape Ann, stations 10490 and 10503, fig. 164, and 33.93 per mille in the northeastern side). However, the submarine rim of the Bay of Fundy, in the one side of the gulf, and the partial inclosure of the trough west of Jeffreys Ledge, in the other, hinder free exchange of bottom water in midwinter as effectively as they do in summer (p. 776), for the salinity was only 32.87 per mille at 150 meters to the west of Jeffreys Ledge, contrasting with 33.75 per mille in the open basin to the east of it. The difference was nearly as great between the Bay of Fundy and the open gulf, off its mouth, at this same level (32.75 per mille at station 10499; 33.37 per mille at station 10502).

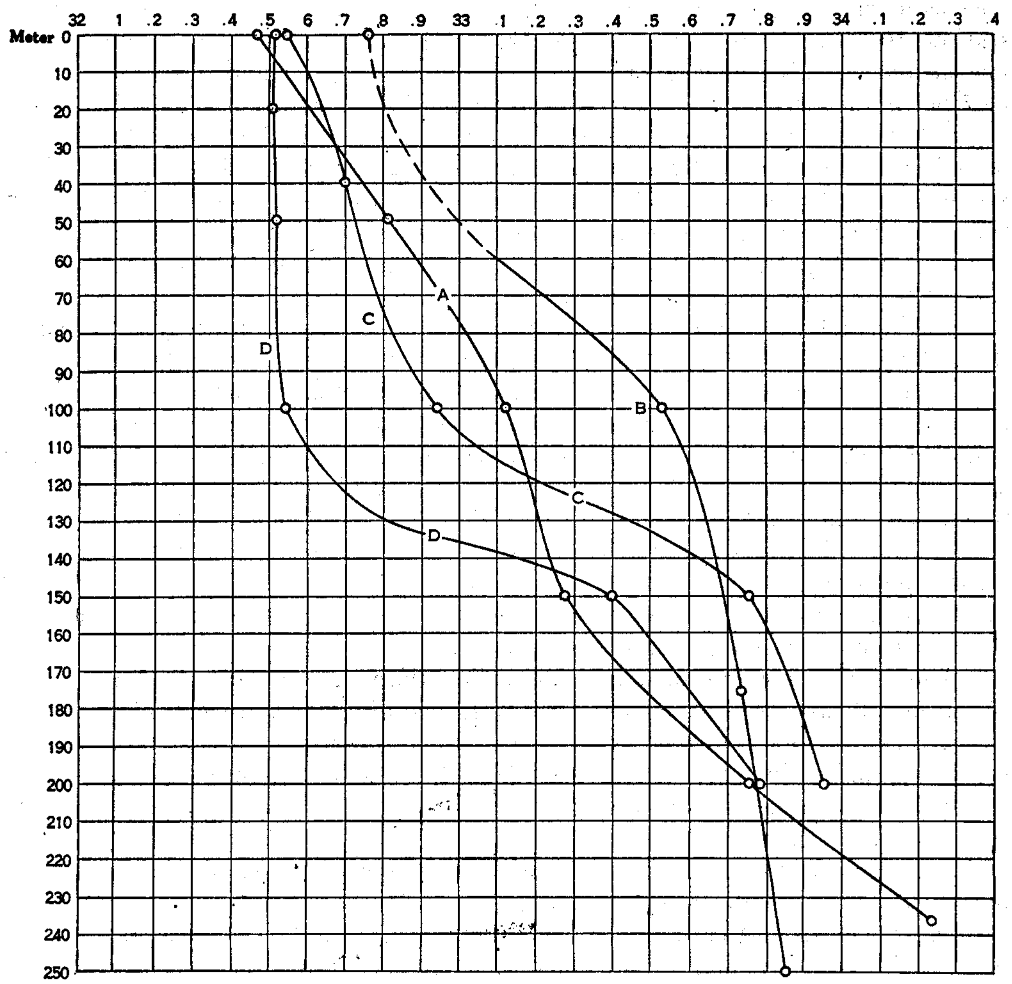

FIG. 164.—Vertical distribution of salinity in the western side of the basin in the offing of Cape Ann. A, August 31, 1915 (station 10307); B, December 29, 1920 (station 10490); C, January 9, 1921 (station 10503) D, February 23, 1920 (station 20049)

We have found this same general rule applying equally to the deep bowl off Gloucester at all other seasons; but on December 29, 1920, the deep strata were much more saline there (station 10489) than were corresponding levels in the open basins, whether off Cape Ann (station 10490) or off Cape Cod (station 10491); more saline, too, than at a neighboring location at any time during the winter of 1912–13. If these determinations were correct,[9] they mean that bottom water had been welling up into the bowl from greater depths in the basin at some time shortly previous. However, this movement had then ceased, and the inequalities in salinity were decreasing; otherwise the temperature would have been about the same at the surface as in the deeper layers (6.9° to 7°), instead of more than 1° lower (5.56° at station 10489). It is certain, also, that the unexpectedly high salinity did not persist long at this locality, for the whole column of water had freshened to 32.6 to 32.7 per mille there by the 5th of the following March (station 10511).[10]

Nor did any upwelling that may have taken place off the mouth of Massachusetts Bay in December, 1920, involve the inner parts, for the whole column of water proved decidedly less saline off Boston Harbor on the 29th (station 10488) than at the mouth of the bay (station 10489); less saline, too, than near Gloucester on January 30, 1913 (station 10051), when salinity ranged from 32.56 per mille at the surface to 32.8 per mille on bottom.

During this midwinter the salinity of the superficial stratum of water was lowest (31 to 32 per mille) along the shore between Cape Ann and Cape Elizabeth, on one side of the gulf, and next the west coast of Nova Scotia, on the other, with a minimum of 30.02 per mille a few miles south of the mouth of the Merrimac River, no doubt reflecting the freshening effect of the latter, but slightly higher along the northern shore of the gulf (32.3 to 32.6 per mille) and in Massachusetts Bay (32.1 to 32.5 per mille). This regional distribution was paralleled at 40 meters (though with actual values averaging about 0.3 per mille higher), except that the minimum for this level was close to the Nova Scotian coast (31.3 per mille) instead of off the Merrimac River, proving the freshening effect of the latter to have been confined to the uppermost stratum of water at the time.

The narrow confines of water less saline than 32 per mille in midwinter, and the rather abrupt transition in the western side of the gulf to considerably higher values a few miles out at sea, contrasted with the much more extensive area inclosed by that isohaline in April and in May (figs. 101 and 120), reflect the fact that the rivers discharge much less water into the gulf in late autumn and early winter than they do in spring.

During the winter of 1912–13 the vertical stratification of the water at the mouth of Massachusetts Bay, characteristic of the summer season, gave place to a close approach to vertical homogeneity in salinity, as well as in temperature, by the middle of December, and so continued through the winter. Closer in to the shore, however, on both sides of Cape Ann, a greater vertical range of salinity persists into January and probably right through until spring.[11] In 1920–21 all the stations showed a vertical range of more than 0.3 per mille salinity in the upper 100 meters, except off Yarmouth, Nova Scotia, and off Cape Cod (stations 10501 and 10491), where the water was virtually homogeneous, surface to bottom, and near Seguin

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[9] There is no technical reason to doubt their accuracy.

[10] In 1913 the salinity at a near-by locality continued to increase until Mar. 19, when it attained its maximum of 33 per mille at the surface and 33.17 per mille on bottom at a depth of 88 meters.

[11] Vertical range of 0.3 to 0.7 per mille in depths of 30 to 35 meters at stations 10051 and 10052 on Jan. 30, 1913.

Island (station 10495), where the salinity increased only from 32.6 per mille at the surface to 32.77 per mille at 75 meters.

Local freshening of the surface, just described (p. 806), was then responsible for the very considerable vertical range of 2.6 per mille in water only 30 meters deep between Cape Ann and the Merrimac River, with differences of 0.8 to 1.4 per mille between the surface and the 75 to 100 meter level off Cape Elizabeth and off Cape Ann (stations 10488, 10489, 10492, and 10494).

It is certain, however, that as the surface continued to cool during that winter the decrease in vertical stability was accompanied by a progressive equalization of salinity in the upper 100 meters; for the surface and the 100-meter level differed by less than 0.2 per mille in salinity at five out of seven of the stations for the following March (stations 10505 to 10511). Thus, the seasonal cycle was fundamentally the same in this respect in 1920–21 as in 1912–13, except that it was more tardy in its early progression.

No general survey of the salinity of the gulf has yet been attempted during the last half of January or the first half of February—on the whole the coldest season (p. 655). However, periodic observations taken in Massachusetts Bay during this period of 1913, hydrometer readings taken at 15 stations by the *Fish Hawk* in its southern side on February 6 and 7, 1925, and Mavor's (1923) winter records for the Bay of Fundy in 1916 and 1917 show that no very wide change is to be expected in the salinity of the gulf during the last half of the winter.

These *Fish Hawk* determinations ranged from about 32.3 per mille to about 33.3 per mille, according to the precise locality, averaging lowest in the hook of Cape Cod, where the surface was about 32.3 to 32.4 per mille, and highest in the center of the bay (whole column close to 33 per mille, surface to bottom). The maximum difference in salinity between surface and bottom was then only 0.4 per mille (average difference about 0.2 per mille), with the water virtually homogeneous, surface to bottom, at the two deepest stations (about 70 meters deep).

It is interesting to find the salinity of the deeper part of the bay for February 7, 1925, almost exactly reproducing the values recorded off Gloucester on the 13th of the month in 1913 (station 10053, surface 32.83 per mille, bottom 32.84 per mille); evidently neither of these winters, as contrasted with the other, can be described as "fresh" or "salt" in the bay. In both 1913 and 1925 the water away from the immediate influence of the shore line was equally homogeneous in salinity from top to bottom by these dates; but the data for the two years combined bring out a decided regional difference in this respect, with the surface continuing 0.3 to 0.4 per mille less saline than the deeper strata along the northern and southern margins of the bay, no doubt because of land drainage.

Although we have made no offshore stations in the gulf between the middle of January and the last week of February, some knowledge of the ebb and flow of the slope water over that period is obtainable from the seasonal progression from February to March in the deeper parts of Massachusetts Bay, and from the salinity of the basin off Cape Ann for March 5, 1921 (station 10510), compared with the preceding December and January (stations 10490 and 10503).

In 1913 the salinity rose to about 32.8 per mille at the surface, to 32.9 per mille on bottom in 70 meters, at the mouth of the bay by January 16—a mean increase of about 0.2 per mille for the preceding six weeks. Apparently this indraft of saline water from offshore then slackened, for on February 13 the water (then virtually homogeneous, top to bottom) still had this same salinity. It then salted once more to 33.04 per mille on the bottom by March 4 (no change at the surface), with a slight further increase during the next two weeks to 33 per mille at the surface and 33.17 per mille on bottom, which proved the maximum for the year, succeeded by the vernal freshening already described (p. 723).

In 1925 the salinity of the deep central part of the bay remained virtually unchanged from February 7[12] until March 10, at about 33 per mille, surface to bottom.

In 1921 the bottom of the basin off Cape Ann showed no appreciable alteration in salinity from December and January to March, with bottom readings of 33.87 to 33.99 per mille at all three of these stations (10493, 10503, and 10510) in depths of 200 to 250 meters; but the bottom water of the bowl at the mouth of Massachusetts Bay off Gloucester freshened by about 1 per mille (stations 10489 and 10511, 33.84 and 32.7 per mille).

It is doubtful, therefore, whether any appreciable drift inward over the bottom of the gulf took place during the winters of 1921 or 1925; and while rising salinity gave evidence of some such movement into Massachusetts Bay in the winter of 1913, the alteration from month to month was so small as to prove it small in volume as well as intermittent in character. In the Bay of Fundy, again, according to Mavor (1923, p. 375), salinity decreased slightly between January 3 and February 28 in 1917.[13] In short, such evidence as is available suggests that the winter sees a decided slackening of the drift of slope water inward through the Eastern Channel.

SUMMARIES OF SALINITY FOR REPRESENTATIVE LOCALITIES

Summaries of the annual cycle follow for localities where the greatest number of observations have been taken. Unfortunately, none of these stations in the open gulf afford a complete year's cycle at intervals close enough, either in time or in depth, to be more than preliminary, but at the least they will serve to illustrate the major changes to be expected from season to season and from the surface downward.

BAY OF FUNDY

Mavor's (1923) records of salinity on 18 occasions, covering the interval from August 25, 1916, to May 10, 1918, at a station near the mouth of the Bay of Fundy, between Grand Manan and Nova Scotia, are especially instructive in this connection. The outstanding event in the annual cycle of salinity here is the sudden freshening of the surface that takes place in spring (fig. 165), occasioned by the outpouring of fresh water from the rivers emptying into the bay—chiefly from the St. John. This occurred between the 10th of April and the 10th of May in both of these years (probably the usual date). As described above (p. 743), the surface then salts again as the thin stratum so affected mixes with the salter water from below,

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[12] No salinities were recorded prior to that date during that winter.

[13] *Prince* station 3, Jan. 3, salinity 32.6 per mille at the surface, 33.24 per mille at 100 meters, and 33.33 per mille at 175 meters, while on Feb. 28 the values at these same depths were 32.66, 32.97, and 33.01 per mille.

to reach its maximum for the year in October (as in 1917) or November–December (as in 1916)—an annual difference no greater than might be expected in any coastal region where the precise salinity is so largely governed by the volume of river water.

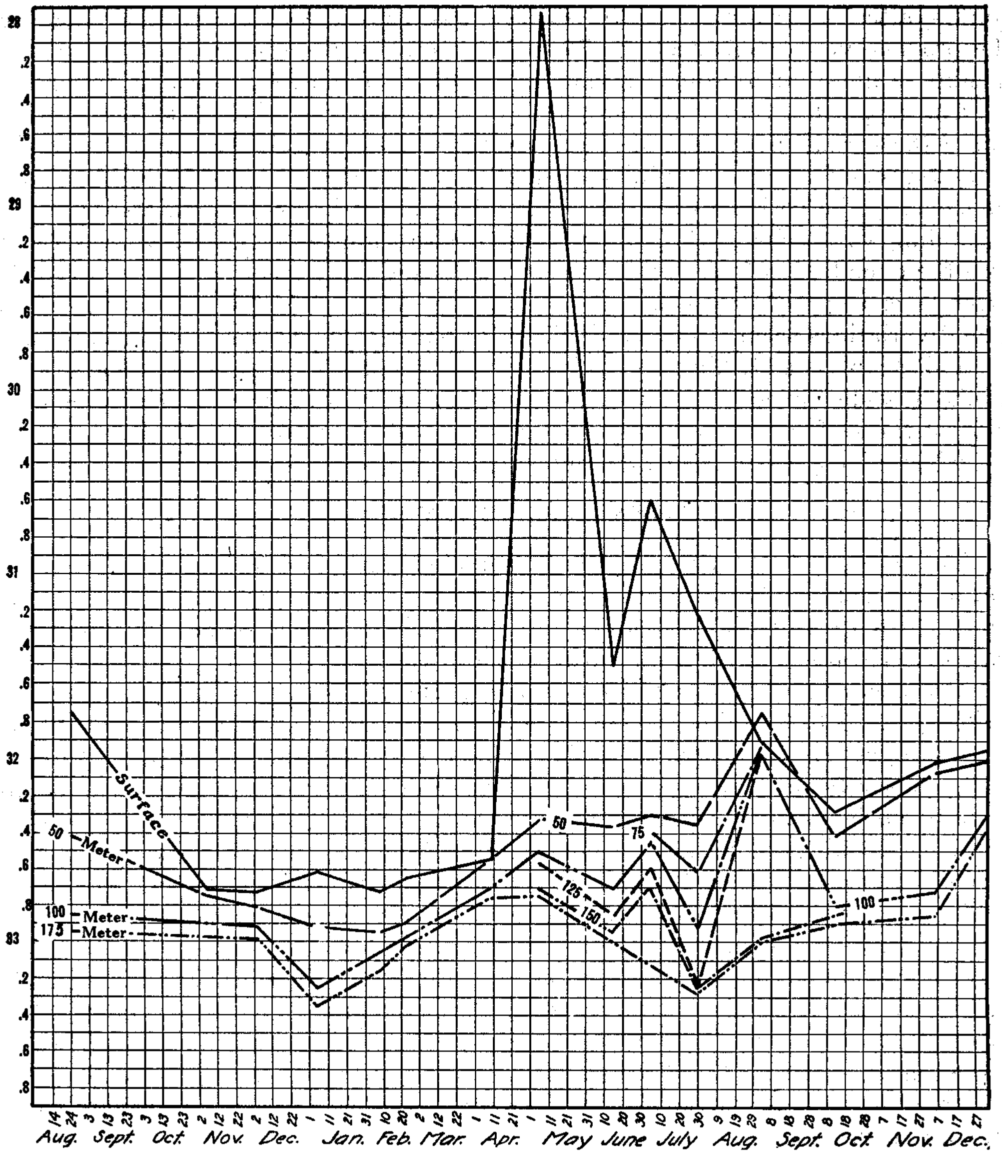

FIG. 165.—Seasonal variations of salinity in the Bay of Fundy, August, 1916, to December, 1917, at the surface, 50 meters, 100 meters, and 175 meters, constructed from Mavor's (1923) tables

During the remainder of the year the surface salinity of this part of the bay is comparatively uniform.

Vernal freshening is progressively less and less effective with increasing depth, so that the salinity of the 50-meter level decreased only by about 1.2 per mille from its maximum to its minimum during the year illustrated, the 100-meter level by about as much, though the surface freshened by upwards of 4 per mille. This secular change also culminates later in the season with depth, just as vernal warming does (p. 664), with the mid-stratum least saline about the first of September or four months after the salinity of the surface has passed its minimum for the year. The progressive freshening of the 75 to 100 meter stratum was also interrupted in the July in question by some temporary welling up of more saline water from below.

The graph (fig. 165) is also instructive for its demonstration that the incorporation of the vernal outpouring of river water into the superficial strata of the bay has little, if any, effect on the salinity at depths greater than about 140 to 150 meters. Consquently the periodic variations that take place in its deepest waters reflect corresponding variations in the volume and precise salinity of the inflow over its rim from the open basin of the gulf outside. Slight undulations in the curve for the 175-meter level (fig. 165) show a sort of irregular pulse in this respect, in which the annual variations seem (from available data) wider than the seasonal variations.

This graph is a striking illustration of the general rule that the vertical range of salinity is widest in coastwise boreal waters, generally, at the time of the vernal freshening of the surface; narrowest in autumn and winter, when little land water enters and when winds, waves, and tidal currents stir the water most actively.

MASSACHUSETTS BAY REGION

The regional distribution of salinity in and abreast of Massachusetts Bay is such that a difference of 3 to 5 miles in the location, nearer to or farther from shore, is associated with wide differences in salinity, especially at the surface, so closely does the freshest water hug the land during most of the year.

The accompanying composite graph (fig. 166), based on monthly averages for various years 8 to 12 miles of Gloucester, is offered as an approximation of the seasonal progression to be expected in years neither unusually salt nor unusually fresh, unusually late in seasonal schedule nor unusually early;[14] and it pretends to nothing more. It does not represent any one year; in fact, some of the individual readings have differed considerably from the smoothed curve laid down here, differences reflecting the annual variations described in the preceding pages.

The curve for the surface corroborates an earlier graph, based on less extensive data (Bigelow, 1917, p. 207, fig. 42), to the effect that the superficial stratum of water may show vernal freshening as early as the end of February or a month earlier than in the Bay of Fundy (p. 808); but additional records for the spring months have proven that the minimum salinity for the year is to be expected considerably earlier in the season in Massachusetts Bay than I formerly supposed, and that the salinity falls to a much lower value there at its annual minimum. It is a fortunate chance that our survey has included one spring (1920) that may be described as "fresh" in this region, and one (1925) as "salt." These two years differed little during the first half of April (p. 728; 32 to 32.4 per mille), and the surface seems to have freshened to its minimum about the last of April or first of May in both years.[15] However, while

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[14] The station occupied at this general locality in July, 1916, is omitted, that being an unusually fresh year.

[15] Observations were not taken at intervals close enough to establish the date more closely than this.

this reduced the surface salinity by at least 3.2 per mille between April 9 and May 4 (29.1 per mille) in 1920, the lowest value recorded at the mouth of the bay in 1925 was 31.3 per mille on April 23 and again on May 22, though it is possible, of course, that the "peak" fell between these two dates, as already remarked (p. 741).

A considerably higher surface value at this locality on May 4, 1915 (station 10266, 32.3 per mille), is reconcilable on the assumption (discussed above) that the effects of vernal freshening were more closely confined to the immediate vicinity of the land in that spring. However, this record is averaged on the graph (fig. 166).

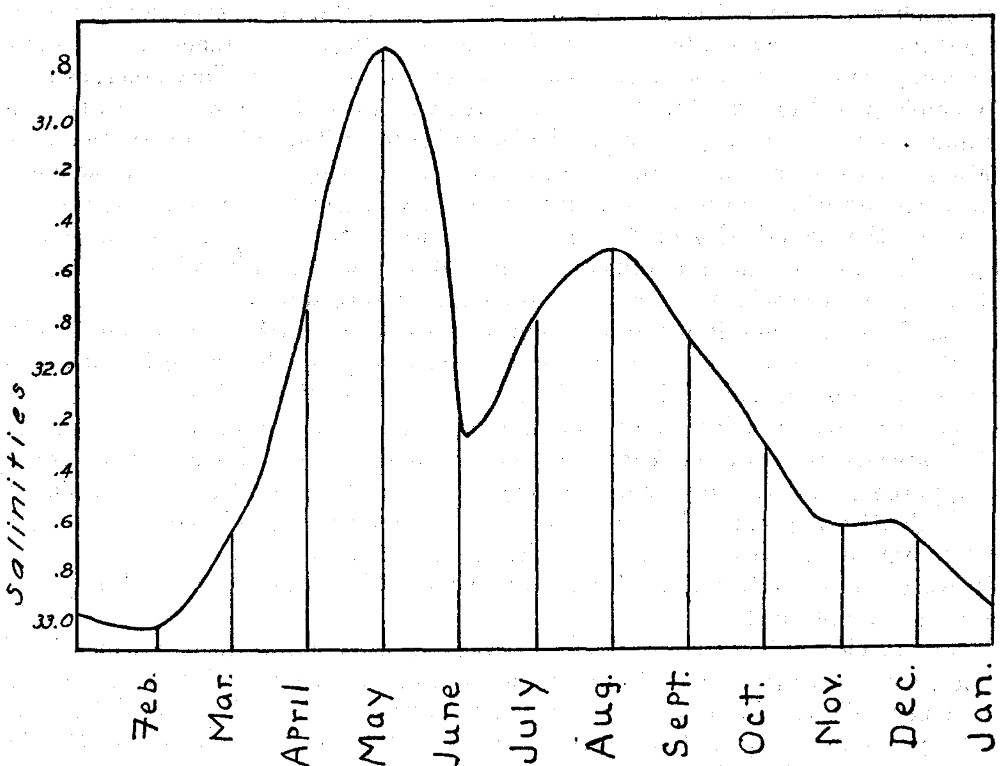

FIG. 166.—Seasonal progression of salinity at the surface at the mouth of Massachusetts Bay, 12 miles off Gloucester, based on monthly averages of the records in the various years. The data for July, 1916, are omitted for the reason given on p. 810

Taking one year with another, the lowest surface salinity of the year is to be expected at this general locality between the last week of April and last week of May. Surface values lower than 31 per mille (sometimes as low as 29 per mille) are to be expected there at some time during this period—a decrease of more than 2 per mille from the maximum salinity at the end of winter.

The vernal freshening at this particular region results chiefly from the discharges from the large rivers to the north (nearest of these is the Merrimac), for no large streams empty in the immediate vicinity. Consequently, any fluctuations in the volume and direction of the drift past Cape Ann will be mirrored by corresponding fluctuations in the salinity of the surface water at the mouth of Massachusetts Bay, and so may confuse the seasonal picture.

In 1925 the surface salinity remained close to the annual minimum at this locality for several weeks (perhaps this is always the case). A considerable increase was then recorded (to about 32.3 per mille; p. 756); but if this is an annual event (which is by no means certain) it is followed by a second freshening, for the surface records for this region for July and August, in the several years of record, have averaged only about 31.5 per mille (or 31.3 per mille, if one station for July, 1916, be included), with 32.09 per mille as the maximum. The salinity then increases slowly through the autumn and early winter, as just described (p. 799). Differences in circulation may bring the surface to its saltest there as early as the last of December, as seems to have happened in 1920 (p. 805), or not until well into March, as in 1913 (p. 808). Comparison between the graphs for the Bay of Fundy (fig. 165) and for the mouth of Massachusetts Bay (fig. 166) brings out the interesting difference that while the surface salinity of the former continues comparatively constant throughout the year, except for the period of 4 or 5 months that covers the vernal freshening and its eclipse, the salinity rises and falls over a period of 8 or 9 months off Massachusetts Bay, with only the winter describable as comparatively static.

The differences in salinity from season to season at the surface are so much wider than the differences at any given season from year to year that inclusion of the latter does not rob the composite graph (fig. 166) of its illustrative value. Annual fluctuations, however, introduce a more and more serious source of error at greater and greater depths, as the effects of vernal freshening from above become less and less apparent, until the former may nearly, if not quite, equal the seasonal fluctuations at depths no greater than 40 meters. Consequently, a combination of the data for different years gives a less trustworthy picture of the seasonal progression for the deep water; and monthly data for any one year, which would yield such a picture, are yet to be obtained.

Nevertheless, when such data as are available are combined, by seasons, for the 40-meter level[16] a rather definite progression does appear, with values averaging 32.8 to 33.1 per mille for the cold half of the year (November through March), decreasing to 32.6 per mille in April, 32.5 per mille in May, 32.3 per mille for July to October, and increasing again through the early winter. While the 40-meter value was as high there on June 16 and 17, 1925 (33.17 per mille), as any recorded for February or March, this is the only record for the period July to October that has been higher than the mean for the year (approximately 32.6 to 32.7 per mille). On the other hand, only 1 of the 10 records for the period January to March has fallen appreciably below the annual mean.

The salinity of the 40-meter level, therefore, may be expected to vary by about 0.7 per mille at the mouth of Massachusetts Bay during average years, being most saline at about the same season that the surface is at its maximum (late winter), but not at its freshest until two or three months after the salinity at the surface has passed its minimum (in May) and begun to increase once more. However, the unusually saline state of the water in this region in June, 1925, is sufficient evidence

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[16] November to January, 6 stations; February to March, 5 stations; April to May, 4 stations; June, *Fish Hawk* cruise 14 in 1925; July to August, 6 stations; September to October, 2 stations for the several years.

that this progression may be interrupted by indrafts of water from offshore, or that the seasonal schedule may vary from year to year.

The 100-meter salinities for this locality have averaged about 32.9 to 33 per mille for the period February to July (extremes 33.8 and 32.5 per mille), with no definite seasonal variation during that period. All but one of the determinations for the period August to October have been appreciably lower (32.5 and 32.6 per mille) than any for the rest of the year, however. An average seasonal varition of about 0.3 per mille is thus indicated at 100 meters, reflecting the extreme depth to which vernal freshening from above is effective; but here, near its lower limit, this freshening does not culminate until a month or two later than at 40 meters, or four months later than at the surface.

The data collected so far fail to show whether any definite seasonal variation of this sort can be traced at depths greater than 100 meters at this locality.

Closer to land, in Massachusetts Bay off Boston Harbor, vernal freshening effects about as great a decrease in the salinity of the surface as at the mouth—from 32.1 to 32.2 per mille in March (of 1920 and 1921) to about 31 per mille in April and to about 30 per mille in May, followed by rather rapid recovery to 31 to 32 per mille through July and August. The lowest values have been recorded as early in the year at 40 meters as at the surface (about 31.6 to 31.7 per mille, April and May, 1920).

OFFING OF THE MERRIMAC RIVER

The truly remarkable extent to which the vernal discharges from the large rivers govern the seasonal cycle of salinity in the coastwise belt of the gulf is illustrated by the offing of the Merrimac. To the southward of the Isles of Shoals, in its train, vernal freshening is as sudden an event and the decrease in the salinity of the surface is as great (by about 4 per mille) as in the Bay of Fundy (p. 808); but in the trough between the Isles of Shoals and Jeffreys Ledge, only some 20 miles out from the mouth of the river, the extreme range of salinity so far recorded at the surface for the months of December, March, April, May, July, August, October, and November[17] has been only about 1.2 per mille (31.6 to 32.8 per mille); nor does vernal freshening seem to culminate there until August—three months later than along shore. Furthermore, its effect is so closely confined to the immediate surface here that it has little effect at 40 meters and is not definitely reflected at all in the records for 100 meters or deeper where the salinity has proved virtually constant from season to season and with but slight variations from year to year.

NEAR MOUNT DESERT ISLAND

The vernal freshening of the surface culminates at about the same season near Mount Desert Island as in the Bay of Fundy—i. e. late in April or early in May.[18] However, this sector of the coast is so much less affected by river water, and so much more open to the offshore waters of the gulf, that the seasonal range

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[17] A total of 10 stations.

[18] Although only 12 sets of salinities have been taken here, the fact that we have records for 6 consecutive months for 1915, and that the other data are consistent with these, makes the graph a reliable picture of the cycle for the half year, May to October, which covers the season when the greatest changes in salinity take place.

of surface salinity is only about one-fourth as wide (about 1 per mille) as in the Bay of Fundy—half as wide as at the mouth of Massachussetts Bay. The surface off Mount Desert then salts again slowly right through the summer and early autumn, its salinity increasing from about 31.5 per mille on May 11, 1915 (station 10275), to to 32.66 per mille on October 9 (station 10328); and while we lack data for November and December it is probable that the surface is near its saltest here during the late autumn and early winter, for readings for January 1, 1921, and March 3, 1920, were somewhat lower and almost precisely alike (32.3 and 32.2 per mille).

The seasonal fluctuation associated with land drainage is strictly confined to the superficial stratum off this open coast, probably because the more saline water in the trough of the gulf tends to bank up along this part of the coastal slope here at all times of year. Thus the highest and the lowest salinities yet recorded at the 40-meter level near Mount Desert are only about 0.4 per mille apart (32.16 per mille, July 19, 1915, station 10302, and 32.6 per mille, August 13, 1913, station 10099). About the same range and the same maximum and minimum values were recorded near bottom at 80 meters, though the water at this depth proved most saline in January (station 10497, January 1, 1921, 32.6 per mille); least so in May (station 10274, May 10, 1915, 32.23 per mille).

GERMAN BANK

The seasonal cycle on German Bank appears from the following summary:

Date	Station	Salinity at the surface	Salinity at 40 meters	Date	Station	Salinity at the surface	Salinity at 40 meters
		Per mille	*Per mille*			*Per mille*	*Per mille*
Mar. 23, 1920	20085	[1]32.60	32.63	Aug. 14, 1912	10029 10030	32.70	32.80
Apr. 15, 1920	20103	32.74	32.79	Aug. 12, 1913	10095	32.75	32.97
Apr. 28, 1919	[2]22	31.70	31.70	Aug. 12, 1914	10244	32.84	32.90±
May 7, 1915	10271	31.89	31.94	Sept. 2, 1915	10311	32.23	32.50
May 30, 1919	[2]38	31.67	31.70				
June 19, 1915	10290	32.07	32.10				

[1] Probably.

[2] Ice Patrol station.

A seasonal variation of at least 1 per mille is thus to be expected there, with the whole column of water least saline sometime between the last of April and first of June, the exact date depending on the flow and ebb of the Nova Scotian current. Data for this part of the gulf during autumn and winter are desiderata.

WESTERN SIDE OF THE BASIN

The extent to which the salinity of the basin of the gulf is affected by the outrush of river water in spring depends more on the tracks of the latter than on the distance offshore. Consequently, the considerable variations that have been recorded in the salinity of the surface of the basin in the offing of Cape Ann from summer to summer no doubt reflect corresponding variations in the volume and direction of the drift from the north past Cape Ann.

In the summers of 1912 and 1914 this drift appears to have been turned sharply offshore by the jutting cape, so that the surface water of the neighboring parts of the basin was about 1 per mille less saline in July and August than the mean value to be expected there in spring. In 1915, however, the surface freshened by only about 0.5 per mille at that locality from May to June; and while salinity may have fallen somewhat lower that July (when no observations were taken), it was about the same there at the end of August (32.5 per mille at station 10307) as it had been in June.

The available data[19] show the surface freshest here in July or August, or three months later than at the mouth of Massachusetts Bay (p. 811), and not saltest until May (p. 745), when the coastwise belt is least saline, a seasonal difference associated with the geographic location.

It is not possible to follow the seasonal progression of salinity in the deeper strata of the basin from the data at hand because the annual variations outrange the seasonal variations even at as small a depth as 40 meters. I can only point out that the 40-meter salinity decreased from 33.15 per mille on May 5, in 1915, to 33 per mille on June 26 and to 32.75 per mille on August 31, suggesting that vernal freshening culminates later at this depth than at the surface, as, indeed, is to be expected. At 100 meters the values for May, June, and August, 1915, all fell close together (33.08 to 33.17 per mille); and the extreme range of variation so far recorded at this level, for all years and seasons, has only been from about 32.5 per mille to about 33.2 per mille in this part of the basin.

Pulses in the indraft of banks water govern the salinity of the deeps of the gulf (p. 848); and these are reflected in fluctuations from a minimum of about 33.5 per mille to a maximum of about 34.1 per mille at the 200-meter level in the basin off Cape Ann. However, as pointed out (p. 852), it is not yet known how regularly periodic these fluctuations are, and if periodic, their exact seasonal schedule.

ANNUAL SURVEY OF SALINITY ON THE BOTTOM

The salinity of the bottom water of the gulf (interesting chiefly for its biologic bearing) is determined in part by the depth and in part by proximity, on the one hand, to the Eastern Channel and on the other to the coastline, with the outflow from its rivers. It is also influenced by the Nova Scotian current and by the general anticlockwise eddy that occupies the basin of the gulf. In inclosed sinks and bowls the degree of isolation is the determining factor.

In summer and autumn the whole bottom of the open basin deeper than 175 meters has invariably proved salter than 33.5 per mille—salter than 34 per mille at most places and on most occasions. In 1914 a maximum of about 35 per mille was recorded for the southeastern part, out through the Eastern Channel (p. 785), but this may have been a somewhat higher value than is usual for that situation. The state of the gulf in the midwinter of 1920–1921 and in the spring of 1920, with the fact that all but two out of 31 records of the salinity of the two arms of the trough deeper that 175 meters have fallen between 33.8 and 34.5 per mille, irrespective of the time of year, make it unlikely that its bottom normally experiences a variation wider than about 0.5 per mille in salinity during the year, or from year to year, in depths greater than 150 meters. Animals living on bottom in deep water in the gulf

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[19] Thirteen stations for the months of February, March, April, May, June, July, August, November, and December in various years.

therefore enjoy an environment that is virtually uniform in this respect from years end to years end. The only exception to this rule has been the eastward of Cashes Ledge, where we have found the salinity of the bottom water only 33.2 per mille in May at a depth of 185 meters (station 10269), contrasting with 33.6 to 34 per mille earlier in spring and in summer.

Certain other regional variations in the state of the bottom water of the trough also can be traced within more narrow limits. Thus, its eastern arm is usually slightly less saline along the western slope than the eastern, independent of depths. In the western arm, however, off Cape Ann, the salinity of the bottom water is more directly a factor of the depth. The salinity on the intervening broken bottom has usually been slightly below 34 per mille; once (in March, 1920) as low as 33.4 per mille. A month later, however, it had risen to 34.18 per mille at this same locality; and water of 34 per mille must overflow the irregular ridge south of Cashes Ledge with some regularity, this being its only route to the basin to the west. An overflow of this sort was, in fact, reflected by an increase in the bottom salinity there from 33.4 per mille on March 20, 1920, to 34.18 per mille on April 17 at depths of 175 to 200 meters (stations 20052 and 20114).

An unmistakable, if slight, increase in the bottom salinity, depth for depth, is characteristic of the floor of the gulf from the inner parts of its two troughs out to the entrance to the Eastern Channel, probably at all seasons.

We have found the bottom salinity of the depth zone between the 175 and 150 meter contours (narrow everywhere except north of Cashes Ledge) averaging about 33.6 per mille, winter and summer, ranging from occasional values close to 35 per mille (or even slightly higher) at the deeper level to a mean of about 33.3 per mille at the shoaler boundary. No definite seasonal variation is demonstrated in water as deep as this, but the recorded variations, station for station, are associated with the pulses in the inflowing bottom current (p. 690).

This depth zone is interesting, however, because it includes the isolated bowl at the mouth of the Massachusetts Bay, the trough west of Jeffreys Ledge, and the deeper parts of the Bay of Fundy, in all of which the bottom water is considerably less saline than at corresponding depths in the open basin outside. In the most nearly inclosed of the three—off Gloucester—the bottom water at any given time of year is virtually uniform from a depth of about 100 meters (slightly below the level of the inclosing rim) down to 170 meters.

Regional differences in salinity increase greatly at depths less than 150 meters as the water shoals, depending on the geographic location, with the changes of the seasons also governing the bottom salinity more and more, so that the picture becomes increasingly complex.

In the coastal zone between Cape Cod and Cape Sable the bottom salinity, at depths of 100 to 150 meters, has been found to vary from 32.38 per mille to 34.11 per mille, according to depth, locality, and date. On the whole it averages lowest in the bowl off Gloucester, in the trough west of Jeffreys Ledge, and in the Bay of Fundy (32.2 to 33.2 per mille for this depth zone); highest on the northeastern slope of the open basin near Lurcher Shoal, where we have had one bottom reading as high as 34.11 per mille in water only 120 meters deep (station 10245, August 12, 1914), with others of 33.4 to 33.8 per mille. The upper part of this depth zone also shows the seasonal effects of land drainage and of the Nova Scotian current. Thus, we have found the bottom of the Northern Channel freshening from about 33.6 per mille in March, 1920, to 32.8 per mille in April at 125 to 135 meters, with 32.9 per mille in July, 1914. Off Lurcher Shoal, where the bottom salinity has averaged about 33.7 per mille at the 100-meter contour in August and September, 33.5 per mille, March to April, and 33.08 per mille on January 4, 1921, it was only about 32.3 per mille at 90 meters on May 10, 1915 (fig. 108).

The bottom salinity of the northern and western sides of the gulf ranges from about 32.3 to 32.5 per mille along the 100-meter contour in August to 32.5 to 33 per mille in winter, according to the precise locality; and the 100 to 150 meter zone along the northern slopes of Georges Bank (here only a few miles wide) is close to 33 per mille in spring, summer, and at the end of the winter, with no definite seasonal variation demonstrable from the observations taken there so far.

On the seaward slope of Georges Bank these depths include the so-called "warm zone" (p. 530), the salinity of which has been sufficiently discussed in the preceding pages. I need only add here that it varies from about 34 per mille to upwards of 35 per mille, hence is considerably more saline than the corresponding depths anywhere within the gulf.

The zone included between the 40 and 100 meter contours is especially interesting because it comprises most of the important fishing grounds, both within the gulf, on Browns Bank, on all but the shoalest parts of Georges Bank, the South Channel, and the outer part of the continental shelf.

The bottom readings for July and August at stations so shoal have varied between 31.8 and 33.2 per mille around the western and northern slopes of the gulf, with 32 to 33.2 per mille on bottom in 40 to 140 meters at our June to August stations at the mouth of Massachusetts Bay.

Close in to the western shore of Nova Scotia, Vachon's (1918) record of 31.09 to 32.33 per mille at 40 to 45 meters off Yarmouth show the bottom averaging somewhat less saline, depth for depth, than in most other parts of the gulf. Bottom salinities are also low off Cape Sable (32 to 32.3 per mille in 50 to 55 meters in July and August, 1914). In the open Bay of Fundy, Mavor (1923) had 31.9 to 32.9 per mille in depths of 50 to 100 meters in August, 1919, while Vachon (1918) records bottom salinities of 31.13 to 32.4 per mille at 45 to 55 meters in St. Marys Bay and 31.2 to 32.2 per mille in 40 to 70 meters depth in Passamaquoddy Bay in the summer of 1916. It is an interesting question, for future solution, whether the bottom salinity of Penobscot Bay and Frenchmans Bay is equally low or whether enough water drifts inward along their troughs to maintain bottom salinities as high as off the open coast.

Little change seems to take place in the bottom salinity of the 40 to 100 meter depth zone along the northern slope of the gulf in autumn, winter, or March. Thus, 14 stations between Cape Cod and the Bay of Fundy averaged about the same at 25 to 80 meters in September and October (32.4 per mille) as in summer, with 4 stations east of Cape Elizabeth averaging 32.7 per mille (extremes of 32.8 and 32.6 per mille) in the midwinter of 1920–21 at 60 to 100 meters. The bottom values for this sector in March, in equal depths, have been 32.4 to 32.5 per mille. Close agreement between the bottom salinity at 40 meters off Yarmouth on January 4, 1921 (31.3 per mille, station 10501), and Vachon's summer records for that locality (p. 769) suggest equal constancy as characteristic of the Nova Scotian side from late summer to midwinter.

Vernal freshening by the rivers and by the Nova Scotian current affects but slightly even the shoaler part of the 40 to 100 meter bottom zone, as described above (p. 750)—the deeper parts hardly appreciably (p. 752). In Massachusetts Bay this event is reflected in a decrease in salinity by about 0.3 to 0.4 per mille from March to May (p. 813), the Bay of Fundy (p. 809) and the eastern side of the gulf, as exemplified by German Bank (p. 814), freshening somewhat more; but it is doubtful whether any vernal freshening of the bottom water from this source is appreciable along the sector between Cape Elizabeth and Mount Desert at depths greater than 100 to 120 meters, except close in to the mouths of rivers (p. 814).

At the end of the winter and in spring we have found the bottom water at this depth varying from 32.5 per mille to about 33 per mille in salinity on the offshore banks, also; and in some years (1916, for example) bottom salinities no higher than this prevail up to the third week in July—perhaps later still; but in other summers (typified by 1914) when slope waters creep in over the shelf during the first two months of summer it raises the bottom salinity to 34 to 34.9 per mille along the southern (offshore) edge of Georges Bank and on Browns Bank.

The zone shoaler than 40 meters falls naturally into two divisions, the one including the waters immediately fringing the coast line of the gulf, the other the greater part of Nantucket Shoals and the shoals on Georges Bank. This zone extends right up to tide line within the gulf, including the shoal bays and river mouths; hence, its bottom water ranges in salinity from brackish, on the one hand, to maximum values of about 32.9 per mille toward its lower boundary, on the other, and experiences the full effects of seasonal freshening. Very little attention has yet been paid to the salinity of this zone around the open gulf; but our stations in Massachusetts Bay in August, 1922, with the Canadian data for the Bay of Fundy region, added to such other evidence as is available, point to about 31 to 32.5 per mille as the usual limits to the bottom salinity at 10 to 40 meters depth in summer and autumn all along the open shores from Cape Cod to Cape Sable, including Casco Bay and the Bay of Fundy. Considerably lower bottom salinities are to be expected over this depth zone in estuaries into which large rivers empty; Vachon (1918), in fact, has recorded values of 28.22 per mille to 31.49 per mille at the mouth of the St. Croix River, varying according to precise locality and stage of the tide, with 31.14 per mille at 20 meters in Kennebecasis Bay and 30.2 to 32.6 per mille at 20 meters at the mouth of the Annapolis River for September, 1916.

The zone from the surface down to a depth of 20 to 30 meters is the only part of the bottom of the gulf that experiences a wide seasonal fluctuation in salinity from the vernal freshening of the surface stratum from the land and from the vernal expansion of the Nova Scotian current. In this shallow water, however, the change in salinity from autumn and winter (when it is near its maximum) to May (when, generally speaking it falls to its minimum) is so wide that the bottom fauna must either be comparatively indifferent to the salinity of the water or able to carry out bathic migrations sufficiently extensive to escape them.

No bottom samples have been collected on the shoal parts of Nantucket Shoals, but neighboring stations suggest 32 to 32.5 per mille as the probable values there at 20 to 40 meters for the summer, autumn, and winter—perhaps slightly lower in spring.

ALKALINITY

It has long been known that under normal circumstances sea water is invariably a very slightly alkaline solution. Within the last few years attention has been attracted to the seasonal and regional variations in the precise degree of alkalinity in the sea by the probability that this feature of the aquatic environment may be one of the controlling factors in the biology of marine organisms, especially of the unicellular planktonic forms. Seasonal changes in this respect also afford a possible measure of the activity of diatom and other plant flowerings, and thus of the intensity of life processes in general in the sea, because marine plants increase the alkalinity of the sea water as they draw carbon from the bicarbonates in solution.

This whole question is exceedingly technical; so much so that no convenient measure for alkalinity has yet been devised, the meaning of which would be obvious to any one who had not devoted some attention to the subject. Salinity, for example, is expressed in percentage or per thousand (the more usual terminology), temperature in degrees—expressions sufficiently familiar to be readily understood. The degree of alkalinity, however, usually is stated in terms of the concentration of the hydrogen-ion, which can hardly be expected to bring a concrete image to the mind of anyone not a trained chemist. Perhaps to the marine biologist or to the oceanographer who is not a trained chemist the following quotation in non-technical language may help to clarify the matter:

> The unit of hydrogen-ion concentration is 1 normal hydrogen-ion per liter of water, or about 1 gram of hydrogen-ion per liter. The finest distilled water contains only about 1 gram of hydrogen-ion in 10,000,000 liters of water at about 22° C., and thus its hydrogen-ion concentration is about 10^{-7}. Sea water, however, is alkaline and contains only about a tenth this concentration of hydrogen-ions. (Mayor, 1919, p. 157.)

The symbol "pH" was invented by Sörensen (1909) and has since been widely adopted to avoid the necessity of writing negative exponents, the notations added thereto being—stated in the baldest possible terms—the logarithm of the reciprocal of the true hydrogen-ion concentration.[20] Therefore, the larger the number of pH the less acid or more alkaline is the water, pH 7 being about neutrality, anything below that acid, and anything above that alkaline.

Determinations of the alkalinity of the sea water can be carried out with little difficulty at sea by the colorimetric method.[21]

The colorimetric tubes used on the *Albatross* in 1920 and on the *Halcyon* were prepared especially for us by Dr. A. G. Mayor and used as prescribed by him (Mayor, 1922, p. 63). These give correct readings for pH if the salinity be 32 to 33 per mille, but for higher salinities every additional 1 per mille of salinity requires a

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[20] For a fuller explanation of the reason for expressing the hydrogen-ion concentration by the term pH, rather than directly see Mayor (1919 and 1922), Clark (1920), and Atkins (1922).

[21] McClendon, Gault, and Mulholland (1917) and Mayor (1919) give details as to the preparation and use of the comparator tubes for rough and ready use at sea.

correction of −0.01 of pH, and a correction of +0.01 for every 1 per mille by which the salinity falls below 32 per mille, thus:

Salinity, per mille	Correction to pH
29	+0. 03
30	+0. 02
31	+0. 01
32–33	0
34	−0. 01
35	−0. 02

For use on shipboard, where conditions of light and shade are not always of the best, and where the lurching of the vessel may make it difficult to handle delicate apparatus, a dark comparator box, in which three tubes can be inserted—the sea water to be tested and a standard on either side of it—much facilitates the comparison of slight differences of color. We have made the following series of determinations from the *Albatross* and *Halcyon*. Accuracy can be expected to ±0.05 of pH, my experience corroborating Mayor's (1922, p. 65) statement that differences as small as 0.03 pH can be detected with the particular colorimetric tubes employed.

Albatross stations

Station	Date	Depth	pH corrected	Salinity, per mille	Temperature °C.
42° 20′ N. by 70° 40′ W	Mar. 10	Surface	7. 9	32. 00	
42° 17′ N. by 70° 07′ W	do	do	7. 9	32. 43	2. 22
42° 12′ N. by 69° 06′ W	do	do	7. 9	32. 65	2. 22
20063	Mar. 11	do	7. 9	32. 61	3. 61
	do	190 meters	7. 88	34. 61	4. 63
20064	do	Surface	7. 9	32. 84	3. 5
	do	330 meters	7. 98	34. 78	4. 02
20065	do	Surface	7. 9	32. 63	3. 61
	do	80 meters	7. 9	32. 69	2. 73
20066	do	Surface	7. 9	32. 57	3. 33
	do	70 meters	7. 9	32. 59	3. 53
20067	Mar. 12	Surface	7. 9	32. 68	3. 05
	do	90 meters	7. 9	32. 79	2. 80
20068	do	Surface	7. 9	32. 65	3. 33
	do	150 meters	7. 9	33. 86	4. 40
	do	190 meters	7. 89	34. 23	4. 92
20069	do	Surface	7. 9	32. 83	3. 33
	do	1, 000 meters	7. 88	34. 92	3. 77
20073	Mar. 17	Surface	7. 9	32. 44	2. 22
20074	Mar. 19	do	7. 9	32. 09	1. 39
	do	150 meters	7. 9	33. 69	4. 68
20075	do	Surface	8	31. 80	. 56
	do	90 meters	8	33. 21	3. 76
20078	Mar. 20	Surface	8	32. 45	1. 95
20079	Mar. 22	do	7. 9	32. 56	2. 50
	do	200 meters	7. 9	33. 31	4. 29
20082	Mar. 23	Surface	7. 9	32. 59	2. 67
20083	do	do	7. 9	32. 17	1. 95
20085	do	do	7. 9		2. 50
20087	Mar. 24	do	7. 9	32. 49	3. 05
	do	250 meters	7. 89	34. 22	5. 06
20089	Apr. 6	Surface	7. 96	31. 25	3. 05
20090	Apr. 9	do	7. 9	32. 36	3. 33
	do	120 meters	7. 9	32. 48	2. 25
20091	do	Surface	8	31. 97	3. 33
20092	do	do	7. 94	31. 01	3. 05
20095	Apr. 10	do	8. 02	30. 07	3. 05
20096	do	do	8. 02	29. 94	2. 78
20098	Apr. 11	do	7. 95	32. 39	3. 05
20099	Apr. 12	do	7. 99	31. 46	3. 61
20103	Apr. 15	do	7. 9	32. 74	3. 89
20104	do	do	7. 9	32. 32	3. 05
20107	Apr. 16	do	7. 9	32. 34	3. 33
20108	do	do	7. 9	32. 58	4. 17
	do	130 meters	7. 9	33. 05	3. 75
20109	do	Surface	7. 9	32. 65	4. 17
	do	150 meters	7. 88	34. 54	6. 47

Albatross stations—Continued

Station	Date	Depth	pH corrected	Salinity, per mille	Temperature °C.
20112	Apr. 17	Surface	7.9	32.54	3.61
20113	do	do	7.9	32.50	3.33
20116	Apr. 18	do	8	32.14	3.61
	do	195 meters	7.9	33.91	4.25
20117	do	Surface	8	31.87	3.61
20118	Apr. 20	do	8.05	31.55	4.44
20121	May 4	do	8.18	29.08	5.56
	do	60 meters	8.15	32.24	2.39
20122	May 8	Surface	8.19	28.26	7.22
	do	85 meters	7.9	32.38	2.30
20123	May 16	Surface	8.02	29.94	8.89
	do	55 meters	7.9	32.18	2.35
20124	do	Surface	7.93	29.87	9.72
	do	100 meters	7.9	32.45	2.65
20125	do	Surface	7.92	30.25	9.17
	do	140 meters	7.9	32.21	4.04
20126	May 17	Surface	7.9	31.53	8.33
	do	160 meters	7.9	33.49	4.10
20127	do	Surface	7.9	31.89	7.22
	do	145 meters	7.9	32.98	3.80
20128	do	Surface	7.9	32.98	7.78
	do	70 meters	8	32.50	5.04
20129	do	Surface	7.9	32.61	7.78
	do	160 meters	7.88	34.72	8.28
20130	May 19	Surface	8	33.17	12.22

Halcyon stations

Station	Date	Depth, meters	pH corrected	Salinity, per mille	Temperature, °C.
10488	Dec. 29, 1920	Surface	7.9	31.82	3.89
10631	Aug. 22, 1922	do	8	31.29	17.80
10632	do	do	8	31.21	18.00
	do	73 meters	8	32.37	4.50
10636	Aug. 24, 1922	do	7.9	31.09	15.80

On March 25 and 26, 1919, Mayor (1922) found the alkalinity to be as follows at several stations between Cape Ann and Yarmouth, Nova Scotia:[22]

Locality	pH corrected	Salinity, per mille	Temperature, °C.
10 miles off Cape Ann	8.04	31.75	4.3
47 miles off Boston Harbor	8	32.54	4.2
Near Cashes Ledge	8	32.56	3.5
32 miles off Yarmouth	7.96	31.46	2.2
8 miles off Yarmouth	7.06	31.67	1.4

Henderson and Cohn (1916) found the alkalinity of several Gulf of Maine samples to vary from pH 8.031 to pH 8.102.

Off the Atlantic coast of the United States, between New York and the Tortugas, Mayor (1922) has reported a range of pH from 7.95 to 8.23, noting a characteristic difference between the gray-green coastal water, with a pH of about 8, and the deep blue gulf stream outside the edge of the continent, with a pH upward of 8.2.

The pH as tabulated above shows the Gulf of Maine to fall among the less

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[22] For general summaries of the measurements of pH that have been made in various seas, see Clark (1920), Atkins (1922), and Palitzsch (1923).

alkaline seas, as might have been expected from its comparatively low salinity and temperature. Within the gulf, however, the pH from station to station does not correspond to the differences in salinity or in temperature; neither have I been able find any definite parallelism between the pH and the abundance of diatoms—certainly no decided rise even at the times and stations when these pelagic plants are flowering most freely. In short, the volume of water is too large and its circulation too free for any given flowering to reflect its active photosynthesis by an appreciable local rise in pH.

The fact that in March the deeper of two samples was in several cases the more alkaline, but that in May the reverse was true, may be significant, the phytoplankton being most abundant in the well-illuminated strata near the surface. It is not improbable, also, that a larger number of observations carried out through the the year would reveal a seasonal fluctuation of pH, with the maximum in early spring and summer following the vernal flowerings of diatoms and the summer multiplication of peridinians, such as occurs in the Irish Sea[23] (Moore, Prideaux, and Herdman, 1915; Bruce, 1924).

VISUAL TRANSPARENCY

Measurements of the transparency of the water were taken at 18 stations durthe summer of 1912 with the ordinary "Secchi" disk—a metal plate 14 inches in diameter, painted white, and rigged with a bridle, so that it hangs horizontal. This is viewed through a water glass[24] while being lowered, and the depth at which it disappears from view is recorded.

In the clearest water the disk was visible to 8.2 fathoms, but at most of the stations it disappeared at 4 to 5 fathoms. Local variations in transparency did not parallel the variations in color (p. 823), for while the water was most transparent when bluest, it was not least so where greenest, but where the percentage of yellow was only 20 (station 10038).

The transparency does not measure the penetration of sunlight, for water cloudy with silt or with diatoms may still be translucent, like ground or opal glass, though transparent to only a small degree.

Transparency, in meters

Date, 1912	Station	Transparency	Date, 1912	Station	Transparency
July 11	10004	6.4	Aug. 15	10031	7.3
July 17	10011	11	Aug. 20	10036	7.3
July 23	10012b	11	Aug. 21	10037	7.3
July 24	10014	11	Aug. 22	10038	5.5
July 25	10015	8.2	Do.	10039	11
July 26	10016	6.4	Aug. 24	10040	9.1
Aug. 7	10022	13	Aug. 29	10043	9.1
Do	10023	15	Aug. 31	10044	9.1
Aug. 8	10025	12			

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[23] See Nelson (1924) for an account of rapid diurnal variations of pH in the estuarine waters of New Jersey.

[24] The use of the water glass is necessary to escape the effect of reflections from the surface.

COLOR

The color of the gulf was measured by percentages of yellow[25] during the summers of 1912 and 1913.

As is well known, the water is, as a whole, bluest outside the edge of the continent, greenest alongshore. With only 2 per cent yellow, the water at our outermost station off Nantucket on July 8, 1913 (station 10060), closely approached the pure sapphire blue characteristic of the so-called "Sargasso Sea," of the Mediterranean, and of certain regions in tropical Indian and Pacific Oceans. In our experience the water has never shown as small a percentage of yellow as this anywhere inside the edge of the continent, though with only 5 per cent of yellow off Nantucket Shoals on July 9, 1913, evidently only a slight overflow of tropic water would have been required to produce very blue water. This is the minimum percentage of yellow so far recorded for the Gulf of Maine proper, and three stations for 1913 point to 9 per cent yellow as about normal for the central basin of the gulf.

At the other extreme, we have invariably found the percentage of yellow greatest (27 to 35 per cent) in the coastal belt along the shore of Maine, out, roughly, to the 100-meter contour, with secondary smaller but very green areas (27 per cent of yellow) along the outer side of Cape Cod and in the German Bank region. The greenest water so far recorded has been in Casco Bay, though inclosed locations probably would prove equally green all around the coast line of the gulf. In the western, northern, and eastern parts of the gulf, including the Massachusetts Bay region on one side and the waters off the Bay of Fundy and west of Nova Scotia on the other, the percentage of yellow has usually ranged from 14 to 20.

The Gulf of Maine, like most coastal boreal waters, thus falls among the greener seas, its color agreeing fairly well with that of the English Channel and with the coast water of the Bay of Biscay (Schott, 1902, pl. 36). However, as I have noted in earlier publications (Bigelow, 1914, p. 81; 1915, p. 225), the distribution of color does not exactly parallel either the temperature or the salinity, for while low salinity is reflected in a high percentage of yellow, the most saline part of the basin has not been the bluest. The true key to local variations in color within the gulf is to be found more in variations in the density and character of the plankton and in the amount and nature of the silt which the water holds suspended.

The records for the two years combined show that the color of the gulf changes but little from July to August or from year to year at that season. No measurements of the color have been made at other times of year, but a browner hue is to be expected alongshore when diatoms are flowering actively in spring.

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[25] The color of the sea usually is measured by the "Forel" scale, based on a combination of blue and yellow, the former being 5-gram copper ammonia sulphate + 0. 5 cubic centimeter ammonia in 95 cubic centimeters water; the latter 15-gram potassium chromate in 100 cubic centimeters of water. The combinations used are as follows:

	1	2	3	4	5	6	7	8	9	10	11	12	13
Per cent blue	100	98	95	91	86	80	73	65	56	46	35	23	10
Per cent yellow	0	2	5	9	14	20	27	35	44	54	65	77	90

Various comparators have been devised for use on shipboard. For descriptions of the method employed on the *Grampus* see Bigelow, 1914, p. 38.

Date	General locality	Station	Color in percentage of yellow
1912			
July 10	Off Gloucester	10002	20
11	Near Gloucester	10004	20
13	Off Boston Harbor	10006	20
15	Basin off Cape Ann	10007	14
16	Ipswich Bay	10008	20
16	Northeast of Cape Ann	10009	14
16	Off Hampton, New Hampshire	10010	20
17	Near Isles of Shoals	10011	20
24	Off Kennebunkport	10013	27
24	do	10014	27
25	Casco Bay	10015	27
26	Near Seguin Island	10016	27
27	Casco Bay	10017	35
27	Orrs Island		44
29	Off Casco Bay	10019	20
Aug. 2	Off Monhegan Island	10021	27
3	Penobscot Bay	10021a	27
7	Off Cape Elizabeth	10022	27
7	Platts Bank	10023	14
8	Offing of Penobscot Bay	10025	20
8	Off Matinicus Island	10026	20
8	Near Seguin Island	10026a	20
14	Basin South of Mount Desert	10027	20
14	Basin, east side	10028	20
14	German Bank	10029	20
15	Off Lurcher Shoal	10031	24
16	Off Mount Desert Rock	10032	24
16	Off Machias, Me	10033	35
19	West end, Grand Manan Channel	10035	20
20	Offing of Machias, Me	10036	20
21	Near Mount Desert Island	10037	35
21	Off Isle au Haut	10038	20
1913			
July 8	Off Northern Cape Cod	10057	27
8	Southwestern part of basin	10058	9
9	West side of Georges Bank	10059	20
9	Offing of Nantucket Shoals	10060	5
10	Continental edge, off Nantucket Shoals	10061	2
Aug. 4	Off Chatham, Cape Cod	10085	27
5	Off northern Cape Cod	10086	27
9	Off Gloucester	10087	14
10	Center of basin	10090	9
11	Offing of Penobscot Bay	10091	20
11	East side of basin	10092	9
12	do	10094	27
12	German Bank	10095	27
12	Off Lurcher Shoal	10096	20
13	Off Machias, Me	10098	20
13	Near Mount Desert Island	10099	27
13	Near Mount Desert Rock	10100	27
14	Offing of Penobscot Bay	10101	35
14	do	10102	20
15	Near Isles of Shoals	10104	20
15	Offing of Ipswitch Bay	10105	20

SOURCES FROM WHICH THE GULF OF MAINE RECEIVES ITS WATERS

In few parts of the world is the coast water that bathes the continental shelf as sharply demarked from the oceanic water outside the edge of the continent as it is off the east coast of North America, from the Grand Banks on the north to Cape Hatteras on the south. Not only is the former much colder and much less saline than the latter, but the transition from the one type to the other is often remarkably abrupt. To see the warm sapphire blue of the so-called "Gulf Stream" give place to the cold bottle-green water over the banks is a familiar spectacle to mariners sailing in from sea. While it is unusual to meet as abrupt a transition as Smith (1923, pl. 5) describes for one occasion (March 27, 1922) south of the Grand Banks, where the water changed from a temperature of 1.1° to 13.3° C. (34° to 56° F.) within the length of the ship, and where the line of demarkation between the two waters was made plainly visible on the surface by ripplings, the transition zone from the one to the other is usually compressed within a few miles abreast the Gulf of Maine.

The general characteristics of the coast water in boreal latitudes have been well described by Schott (1912) and are matters of common knowledge. I need merely state here that mean annual surface temperatures lower than 15° and mean salinities lower than about 33.5 per mille may be so classed, as distinguished from the much warmer and more saline (35.5 per mille) tropic water, which is commonly (though rather loosely) termed "Gulf Stream" as it skirts the North American plateau.

In discussing the sources of the sector of the coast water included within the Gulf of Maine, it will be convenient to consider the upper and lower strata separately, for it is now proven they they draw chiefly from different sources.

SUPERFICIAL STRATUM

NOVA SCOTIAN CURRENT

Until detailed study of the physical characters of the coast water off northeastern North America was undertaken by the United States Bureau of Fisheries, the Museum of Comparative Zoology, and the Biological Board of Canada, a northerly source was usually ascribed to the coastal water all along the seaboard of Nova Scotia, New England, and much farther to the south. This, in fact, has been described, time out of mind, as the "Arctic current." As I have remarked in an earlier report (Bigelow, 1915, p. 251), "almost all the ocean atlases show something of this sort; and it has been accepted in one form or another in almost all the textbooks on physical geography and oceanography (for example, Maury, 1855; Reclus, 1873; Attlmayr, 1883; Thoulet, 1904; Krümmel, 1911; Schott, 1912; the German Marine Observatory (Deutche Seewarte, 1882), the current charts of the United States Navy (Soley, 1911), and the British Admirality (1897) current chart.)"

The low temperature of the surface water near shore, contrasted with the "Gulf Stream" offshore and with the oceans as a whole at the latitude in question, naturally suggests a northern origin until analyzed in relation to other factors (p. 686). Ostensible evidence to the same effect is afforded by the continuity of the cold zone all along the northeastern coasts of North America, with its mean temperature gradually decreasing from the south toward the Newfoundland-Baffins Bay region in the north. The southwesterly drift that has been reported repeatedly along the coasts of the northeastern United States and Nova Scotia argues in the same direction; so, also, the extension of a generally boreal fauna southward and westward as far as Cape Cod, with planktonic communities of this category spreading still farther in this direction in winter.

The observations on the temperature, salinity, and circulation of the gulf, detailed in other chapters, do, in fact, prove beyond reasonable doubt that water from the northeast (low in temperature) does flow past Cape Sable into the Gulf of Maine for a time in spring, sometimes into the summer. Before considering what part this actually plays in the Gulf of Maine complex a few words may well be devoted to its probable source.

Up to 1897 the supposed coldness of the coastal water along North America in general, and any definite evidences or reports of a current from northeast to southwest in particular, were usually classed as southward extensions from the Labrador Current. Without much analysis this Arctic stream was generally thought to flow down from the Grand Banks region, past Nova Scotia, and so southward along the whole eastern seaboard of the United States, carrying to New England the cold resulting from the melting of ice (floe and berg) in Baffins Bay or about the Grand Banks. Some such southerly branch of the Labrador Current is taken for granted in most of the older textbooks, charts, and discussions of North American hydrography. Thus Libbey (1891, 1895), in his studies of temperature south of Marthas Vineyard, definitely identified as such the cool band that he recorded along the continental edge in the offing of southern New England. This view was widely held until recently. Sumner, Osburn, and Cole (1913, p. 35), for example, state, on the authority of the United States Navy Department, that the Labrador Current flows from the Grand Banks past Nova Scotia and so southward as far even as Florida, narrowing from north to south. Krümmel (1911) believes the polar water tends to drift southwestward across the Grand Banks and so to Nova Scotia. Engelhardt (1913, p. 9, chart B) did not doubt that the Labrador Current bathes our coasts at least as far as the Gulf of Maine. Johnston (1923, p. 271) describes it as hugging the coast of North America from Halifax to Cape Cod; and as recently as 1924 Le Danois (1924, p. 14) wrote of the "dernierès eaux du courant du Labrador qui longuent la côte des Etats Unis."

On the other hand, Verrill (1873, p. 106; 1874), in the early days of the United States Fish Commission, had maintained that the actual temperatures of the deep strata of the Gulf of Maine did not suggest the effects of any Arctic current, though he qualified this generalization by adding that the gulf receives accessions of cold water, ultimately coming from the north, by the tides.

It is obvious that for the Labrador Current to follow the track usually ascribed to it implies a dominant cold drift setting southwestward from the Newfoundland-Grand Banks region across the oceanic triangle that separates the Newfoundland from the Scotian Banks, and so in over the latter toward the coast; but although a current of this sort is represented on many charts, its supposed extension westward from the Grand Banks to Nova Scotia seems to have been based more on theoretic grounds (the assumed necessity for connecting the cool coastal water to the southward with the Arctic flow from Baffins Bay) than on direct observation. Schott (1897), who first attempted a detailed study of oceanography of the Grand Banks region, also failed to find any dominant set from northeast to southwest across the banks, in spite of the proximity of the Labrador Current, which has long been known to skirt their eastern edge and sometimes to round the so-called "tail of the bank" for a short distance westward and northwestward. He did, it is true, record sporadic movements of this Arctic water in over the banks, but he believed them too small in volume and too irregular in occurrence to be anything but temporary surface currents caused by the northeast winds, which often blow fresh there. His conclusions were based on so many records of temperature and on measurements of the current taken from fishing vessels lying at anchor on the banks that they form the foundation for more modern knowledge of the characteristics of the Labrador Current in the Grand Banks region.[26]

Schott's chief thesis—that the most southerly bounds of the Labrador Current as a definite stream flow lie not far south or west of the "tail" of the Grand Banks—has been corroborated by the extensive oceanographic observations taken yearly by the International Ice Patrol since 1914 (Johnston, 1915; Fries, 1922 and 1923; E. H. Smith, 1922 to 1927; Zeusler, 1926), both in the region of the banks and in the oceanic triangle between the latter and Nova Scotia; also by the drift-bottle experiments carried out by the Biological Board of Canada (Huntsman, 1924).

The data gathered by the Ice Patrol are especially instructive in connection with the Gulf of Maine, both because of their extent and because especial effort has constantly been made to chart any extensions of the Labrador Current that might carry bergs toward the west or southwest—extensions usually easily traceable by their icy temperature, even if carrying no bergs with them at the time. Furthermore, the operations of the patrol cover the part of the year (March to July) when the Labrador Current is greatest in volume as it flows southward and lowest in temperature—hence, when it would be most likely to reach the coast line of Nova Scotia or the Gulf of Maine, if it ever does so.

So many oceanographic sections have now been run in various directions from the tail of the Grand Banks by the patrol in various years, and between the banks and Halifax, with so careful a record of all bergs since 1911, whether actually sighted by the patrol cutter or reported by other ships (E. H. Smith, 1924a, chart M), that it is hardly conceivable that any considerable or constant flow of icy cold water from the Grand Banks region toward Nova Scotia could have escaped attention during the seasons covered.

Actually, however, not a single phenomenon of this sort has been encountered during all the years of the patrol. Thus, Johnston (1915, p. 41), in his report on the operations of 1914, definitely states that "as a stream, Labrador water never gets west of Grand Bank"; consequently, that the name "Labrador Current," as applied to the cold water along the eastern coast of the United States, is a misnomer. Fries (1922, p. 73), in discussing the oceanographic observations during the patrol of 1921, also failed to find any evidence of the Labrador Current continuing westward from the Grand Banks toward the Gulf of Maine. With the accumulated data of successive years, E. H. Smith (1923) describes the Labrador Current as usually reaching its farthest boundary on the south and west, somewhere between latitude 42° and 43°, longitude 51° and 52°, where it eddies sharply to the eastward. A similar account has recently been given by the Hydrographic Office, United States Navy (1926). As this was the case during the spring and early summer of 1923 (a year that may be classed as normal, both in respect to the number of ice bergs that drifted down to the tail of the Grand Banks and to temperature), and again in the ice-free season of 1924, E. H. Smith (1924a, p. 144) seems fully justified in his conclusion that when the Labrador Current recurves westward around the tail of the banks this is "the extreme

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[26] Schott (1897) described small amounts of polar water as turning westward past Cape Race along the south coast of Newfoundland, to enter the Gulf of St. Lawrence via the northern side of Cabot Strait, where an inflowing current (i. e., setting west) has often been reported. More recent studies, however, have made it seem unlikely that it extends so far.

southern extension of the cold polar water."[27] Observers who have actually studied oceanographic conditions first hand in the Grand Banks region are unanimous to this effect.

The evidence of temperature and salinity on which this general thesis rests is set forth in detail in the successive reports of the patrol (see also Bjerkan, 1919; Le Danois, 1924, p. 40, and 1924a, p. 46) and need not be repeated here. I need only point out that any branch of the Labrador Current that might flow southward from the banks would not only be betrayed by its temperature and salinity (p. 829) but it would doubtless carry bergs with it in greater or less number from time to time. Actually, however, not a single berg (except small ones drifting out from the Gulf of St. Lawrence) was reported west of longitude 55° during the period from 1911 to 1924, very few west of longitude 52°, whereas some hundreds came drifting down along the east slope of the Grand Banks during that period (see E. H. Smith, 1924, chart P, showing distribution of ice bergs from 1911 to 1923).

The results of the drift-bottle experiments carried out in eastern Canadian waters within the past few years by the Biological Board of Canada have not yet been published in detail. However, Dr. A. G. Huntsman kindly supplies the information that they give no more suggestion of a definite stream from the Grand Banks toward Nova Scotia than do the temperatures or ice drifts just discussed.[28]

In short, no actual evidence of such a current is forthcoming from recent investigations, but the reverse. I have no hesitation, therefore, in definitely asserting that the Labrador Current does not reach, much less skirt, the coast of North America, from Nova Scotia southward, as a regular event, corroborating Jenkins's (1921, p. 166) statement that it does not reach the coast of the United States. Consequently this is not the direct source of the cold current that reaches the Gulf of Maine from the east. If overflows of the Labrador Current do take place in this direction they are of such rare occurrence that no event of this sort has yet come under direct scientific observation.

As Huntsman (1924, p. 278) points out, a certain amount of the water flowing down from the Arctic may move westward and southwestward along the slope of the continent as a constituent of the slope water (p. 842), so much warmed, however, en route, by mixture with tropic water that if it reaches the Gulf of Maine at all it does so as a warming and not as a cooling agent, and on bottom, not at the surface. Labrador Current water in small amount may also reach the gulf indirectly via the Gulf of St. Lawrence route, shortly to be discussed; but if so, its distinguishing characters as an Arctic current are lost, and it becomes one of the constituents of a coastal current.

The physical characters of the cold band of water that hugs the outer coast of Nova Scotia also forbid the idea that it draws direct from the Labrador Current. According to the observations by the *Scotia* (Matthews, 1914), the records of the Canadian Fisheries Expedition of 1915 (Bjerkan, 1919), and the much more extensive data that have been accumulated during the years of the Ice Patrol, the

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[27] The reader is referred to Smith's chart (1924a, sketch 10, p. 150) for the normal distribution of the Arctic water around the banks in the spring and early summer; also to his general scheme of circulation in the vicinity of the tail (Smith, 1924a, p. 135).

[28] Huntsman's chart (1924, fig. 32) showing the complexity of the circulation between Nova Scotia and Newfoundland includes the most outstanding results of these experiments.

unmixed Labrador Current (temperature below −1°) is colder than the coldest outflow from Cabot Strait, or than the coldest water over the Scotian shelf, which have never been found to fall below −0.5° in temperature. The evidence of salinity, of like import, is even more instructive in this respect, for the undiluted Labrador Current off the Grand Banks is considerably more saline than the cold water next the Nova Scotian coast, being characterized by a salinity of at least 32.5 per mille, while its surface salinity hardly falls below 32 per mille even along its inner edge, where most influenced by drainage from the land (minimum so far recorded about 31.9 per mille; Matthews, 1914).

"From this," as I have stated elsewhere (Bigelow, 1917, p. 236), "it appears that did any considerable amount of unadulterated Labrador water join the Nova Scotia coast current, the temperature of the latter would be lower, its salinity higher, than in Cabot Straits"; whereas both the temperature and the salinity of the cold band skirting the Nova Scotian coast have proved remarkably uniform, from the straits westward to its farthest extension. It is true that an infusion of Labrador Current water (spreading westward from the Grand Banks region) might join the Nova Scotian coast water without lowering the temperature of the latter did it mix sufficiently with the warmer water, which it must needs displace en route, to raise its own temperature by 1° or more. Such a mixture, however, would necessarily raise its salinity as well as its temperature, because the water that normally fills the deep oceanic triangle between the Scotian and Newfoundland Banks is considerably more saline than the Labrador Current, a fact amply demonstrated by repeated profiles run by the Ice Patrol and by the Canadian Fisheries Expedition (Bjerkan, 1919). Hence, if any large amount of such mixed water joined the cold Nova Scotian coast current, the salinity of the latter would be made considerably higher than it actually is, so that salinity would betray the event even if temperature did not. Actually nothing of the sort has been recorded, observations taken by the *Grampus*, the Canadian Fisheries Expedition, and the Ice Patrol uniting to demonstrate that low salinity is as characteristic of the cold band next Nova Scotia as low temperature is. However, the temperatures and salinities taken by the *Acadia* in July, 1915 (Bjerkan, 1919), make it at least highly probable that isolated offshoots, pinched off as it were from the Labrador Current, do occasionally drift westward as far as the continental slope off Banquereau Bank and Cape Sable. Otherwise it would be difficult to account for the pool of icy water (−1.7°) then reported off Sable Island—a pool both colder and more saline (32.82 to 33.08 per mille) than the outflow from the Gulf of St. Lawrence, but which reproduced the coldest water of the Newfoundland Banks in its physical character.

These several lines of evidence forbid the possibility that the Labrador Current is directly responsible for the low temperature of the cold water that reaches the Gulf of Maine from the east. Water from the Labrador Current may reach the Gulf of Maine indirectly via the discharge from the Gulf of St. Lawrence, for a certain amount of this Arctic water may enter the latter along the northern side of Cabot Strait. Huntsman's (1925) recent survey of the Straits of Belle Isle points to a greater inflow of Arctic water by this route than Dawson's (1907) earlier survey had suggested; but even so, it is an open question whether this Arctic contribution is sufficient to lower the temperature of the coldest stratum of the Gulf of St. Lawrence (or of its discharge around Cape Breton) below the point to which winter chilling, *per se*, and ice melting *in situ*, would reduce it.

Schott (1897) and Hautreaux (1910 and 1911), abandoning the Labrador Current, saw in the Gulf of St. Lawrence the source of the cold coast water as far west and south as New York. This view is supported by so much evidence that in earlier publications (Bigelow, 1915, 1917, and 1922) I have described the cold Nova Scotian water that flows past Cape Sable into the Gulf of Maine as probably a direct continuation of the current that is known to flow out through Cabot Strait on the Cape Breton side.

Briefly stated, the evidence on which this view was based stood as follows up to 1922, when Canadian experiments with drift bottles threw new light on the subject:

The enormous volume of fresh water poured yearly into the Gulf of St. Lawrence by its tributary rivers, added to a deep current of slope water flowing in through Cabot Strait on the bottom (Huntsman, 1924), apparently, too, with a balance of inflow over outflow in the Straits of Belle Isle, and with the currents on the north side of Cabot Strait usually inward, while the rain that falls on the surface of the Gulf of St. Lawrence almost certainly exceeds the evaporation therefrom, make it certain that the current flowing out via the south side of Cabot Strait discharges a large volume of water. Experimental evidence substantiates this, for current measurements by the tidal survey of Canada (Dawson, 1913) seemed to establish a constant outflow there, at least 30 miles broad abreast of Cape North, with an average velocity of about half a knot per hour at the surface, which Dawson (1913) termed the "Cape Breton current," but was earlier known as the "Cabot current."

Temperatures and salinities taken by the *Grampus* in the eastern side of the Gulf of Maine, near Cape Sable, and as far east along the outer coast of Nova Scotia as Halifax, in 1914 and 1915, pointed to a direct continuation of this "Cape Breton" or "Cabot" current southwestward alongshore, nearly to the Gulf of Maine, during these summers (Bigelow, 1917, p. 234). Futhermore, a dominant surface drift of ⅓ knot per hour toward the southwest was recorded by the Ekman current meter off Shelburne, on July 27 and 28, 1914 (station 10231), only 30 miles east of the entrance to the Gulf of Maine.

Thus the physical character of the water, combined with readings of the current meter, seemed to show a direct surface drift from the northeast along the Nova Scotian coast between Shelburne and Halifax, distinguishable by a considerable difference in temperature and salinity from the salter, warmer water that bounded it on the seaward side. These characteristics and the fact that we found such characteristically Arctic components as *Limacina helicina* and *Mertensia ovum* among its plankton seemed to classify it as actually the southernmost prolongation of the outflow from Cabot Strait (Bigelow, 1917, p. 357).

Observations taken by the Canadian Fisheries Expedition of 1915 (Bjerkan, 1919) and returns from several series of drift-bottle experiments subsequently carried out by the Biological Board of Canada in the years 1922, 1923, and 1924[29] have proven the circulation over the continental shelf along Nova Scotia to be of a nature much

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[29] Huntsman, 1925, and notes kindly contributed by him

more complex than the simple stream flow from northeast to southwest suggested by the earlier evidence.

The track followed by the ice drifting out of the Gulf of St. Lawrence is especially instructive here in this connection, because this discharge takes place in spring (chiefly in April and May) just when the Nova Scotian current is flooding past Cape Sable into the Gulf of Maine in greatest volume; whereas most of the drift-bottle experiments have been carried out in summer, when this current is usually inactive or at least is carrying so small a volume of water past Cape Sable that it is no longer an important cooling agent for the Gulf of Maine. According to Johnston (1915), the ice that comes out along the Cape Breton side of Cabot Strait does not tend to follow the Nova Scotian coast around to the southwest, as it would if the outflowing current hugged the coastline, but divides. Part drifts out to the southeastward; but the ice that emerges from the gulf nearest the Cape Breton coast moves southward across Banquereau Bank, where it fans out, to the offing of Halifax.

These lines of dispersal correspond very closely with the icy water which Bjerkan's (1919) data for May, 1915, show spreading out from the southern side of Cabot Strait to the region of Misaine and Banquereau Banks (fig. 167), but separated from the still colder (−1°) water on the Newfoundland Banks by a warmer (0°) core in the axis of the Laurentian Channel, and with much higher temperatures off the mouth of the latter. Especially suggestive, from the standpoint of the Gulf of Maine, is the narrow icy tongue (0° to −0.2°) that then extended westward along Nova Scotia past Halifax; a band comparatively uniform, also, in salinity from east to west (31.5 to 32.5 per mille) and considerably less saline than the still colder water on the Newfoundland side of the Laurentian Channel (temperature lower than −1°; salinity 32.7 to 33.2 per mille). This the Ice Patrol cutter had also crossed on her run in to that port about a week earlier (United States Coast Guard stations 26 and 27, May 20, 1915).

Lacking data in the offing of Cape Sable, it is not possible to state whether this cold tongue actually extended to the Gulf of Maine that May, though it may have done so earlier in the season and certainly does so during the spring in some years (p. 681).

A similar concentration of cold water close in to Nova Scotia appears from the temperatures taken by the Ice Patrol along a line from Halifax toward Sable Island in spring in other years. The records for 1919 are especially instructive, showing this band widest at the end of March, when the whole column of water next the land was fractionally colder than zero from the surface to bottom; smaller in volume in April, when it was overlaid by slightly warmer (0° to 1°) water; and shrunken to a narrow tongue on the bottom not more than about 20 miles broad in May.[30]

Drift bottles set out by the United States Coast Guard cutter *Tampa* (Capt. W. J. Wheeler) on April 18, 1924, along a line running 119° (about SE x E½ E.) true from a point about 18 miles southeast of Sable Island (43° 48′ N.; 59° 26′ W.) for 50 miles, likewise show a drift from this region first northward toward the land and then westward toward the Gulf of Maine, three out of the seven returns (all from the inner end of the line) being from Sable Island, one from the Nova Scotian coast not far

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[30] The March profile also cut across the southwestern edge of the icy Cape Breton-Banquereau pool near Sable Island.

from Halifax, and one from Gloucester Harbor, where it was picked up on August 14.[31] Although two of the bottles from this line drifted to Newfoundland, showing a division, this does not detract from the evidence of the Gloucester recovery.

Clearer evidence that the cold tongue that skirts Nova Scotia and flows past Cape Sable into the Gulf in Maine in spring is actually an overflow from the icy pool that develops from Cabot Strait out over Banquereau Bank, when the ice is coming out of the Gulf of St. Lawrence, could hardly be asked than results from the temperatures, salinities, and bottle drifts just discussed.

I believe it now sufficiently demonstrated that while this cold pool (fig. 167) owes its low temperature, to some extent, to the direct outflow of icy water from the Gulf of St Lawrence via the Cape Breton side of Cabot Strait, it more directly mirrors the chilling effect of the field ice from the Gulf of St. Lawrence as this melts in the region between Banquereau Bank and Sable Island. Consequently, cold water that reaches the Gulf of Maine from the east is, in fact, ice-chilled, though this takes place 300 miles or more to the eastward of the eastern portal to the gulf.

It is to this cold band skirting Nova Scotia that the name "Nova Scotian current" is applied in the preceding pages. During the spring a large volume of water enters the eastern side of the Gulf of Maine from this source, producing the effects on salinity and temperature described in the chapters on those physical features; and this is certainly the chief source that contributes cold water of northern origin to the Gulf of Maine—almost certainly the only source making a contribution of this sort sufficient in amount and cold enough to exert any appreciable effect on the temperature of the gulf (p. 682).

This current flows into the gulf in volume during only a few weeks in spring—earlier in some years, later in others. As its fluctuations are referred to repeatedly in the preceding pages a summary will suffice here.

In 1920 (a late season) icy water ($<1^{\circ}$) from this source had spread westward as far as the offing of Shelburne, Nova Scotia, by the last week in March; but neither the temperature nor the salinity of the eastern side of the Gulf of Maine give any evidence that it had commenced to flood past Cape Sable up to that date, nor do the isohalines for that April suggest any drift of water of low salinity into the gulf from the east. The coastal zone, also, warmed about as rapidly in the one side of the gulf as in the other during that month (p. 553). Conditions seem, then, to have remained comparatively static off Cape Sable through the first two months of the spring of 1920, and if the Nova Scotian current discharged at all into the gulf in that year this did not happen until May or later. In 1919, however, an early season, its western expansion culminated before the last of March, and had slackened, if not ceased, by the end of April (p. 558). In this respect 1915 seems to have been intermediate (so may be taken as a representative spring), with the Nova Scotian current exerting its chief chilling effect on the eastern side of the gulf before the first week in May (p. 560), and slackening from May to June, as indicated by the contraction (to the eastward) of the area inclosed by the surface isohaline for 32 per mille (cf. fig. 120 with fig. 128).

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[31] Information kindly supplied by Dr. A. G. Huntsman.

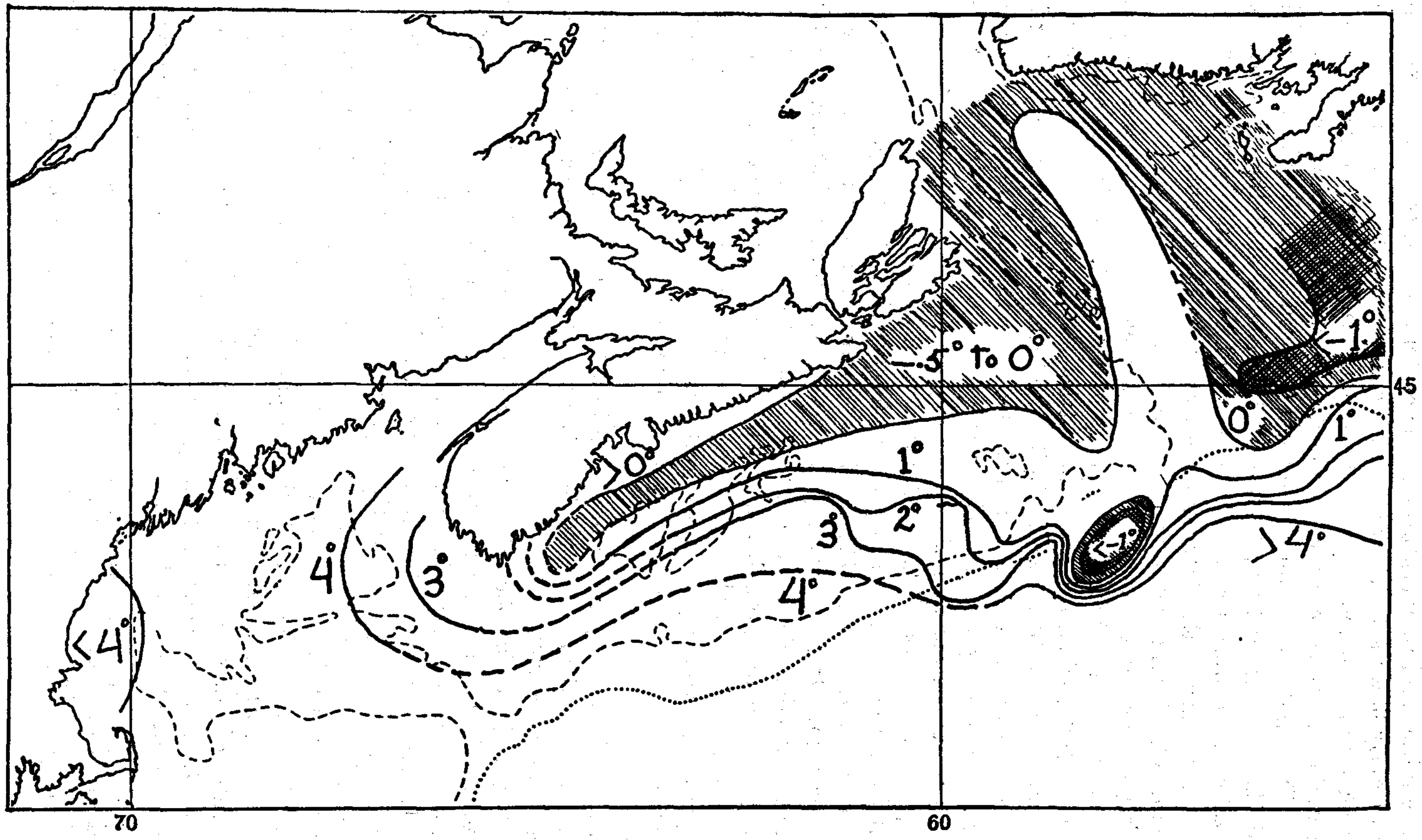

Fig. 167.—Distribution of the coldest water, irrespective of depth, from Newfoundland to the Gulf of Maine, for May, 1915, based on the records of the Canadian Fisheries Expedition (Bjerkan, 1919) and *Grampus* stations 10266 to 10279

The salinities and temperatures of the eastern side of the gulf make it probable that the westerly flow past Cape Sable slackens or ceases by June, at the latest, every year—often a month or more earlier than that. In some years sporadic movements of water undoubtedly take place from east to west past the cape later in the season; but the drift of bottles put out on several lines off Nova Scotia by the Biological Board of Canada during 1922, 1923, and 1924 shows that the circulation over the continental shelf between Browns Bank and the Laurentian Channel becomes exceedingly complex during the late summer, variable from summer to summer, and largely controlled by the contour of the bottom.[32]

During some summers a rather definite current from east to west persists along the Nova Scotian coast right through July and August. This statement is based on the drifts for 1924, when a number of bottles set out on three lines normal to the general trend of the coast between Halifax and the Straits of Canso, during July and August, were picked up in autumn in the Gulf of Maine. Many other bottles from the most easterly lines also traveled westward during that summer but stranded before they reached Cape Sable.[33]

The probable tracks of the bottles that went westward, localized some 12 to 25 miles out from the land, correspond so closely with the tongue of coldest water charted for May, 1915 (fig. 167), that the dominant drift was evidently essentially the same for both. In May, as temperatures show, this east-west movement involved a stratum of considerable thickness; but in the summer of 1924 it was more strictly a surface phenomenon, probably with the underlying water circling offshore along Roseway and La Have Banks in the more usual anticlockwise eddy, because what few temperatures were taken in the gulf that summer (p. 996) suggest no greater transference of cold water (such as a bottom current past Cape Sable would entail) than usual.

The westerly set may again have continued past Cape Sable until September in 1926, when many drifts were recorded from the offing of the cape into the gulf, as summarized on page 909.

The bottle drifts for the other summers of record show, however, that it is unusual for the Nova Scotian current to persist as a definite stream-flow as far west as Cape Sable after June, but that the deep basin between Sable Island Bank on the east and La Have Bank on the west is usually dominated (in summer) by an anticlockwise eddy named by Doctor Huntsman the "Scotian eddy," similar to, though not as extensive as, the eddy that dominates the basin of the Gulf of Maine.

In summers of this type whatever drift takes place intermittently around Cape Sable into the eastern side of the Gulf of Maine draws from what Doctor Huntsman describes as a sort of dead-water region off the cape. True, this, in its turn, receives water of low temperature from the Scotian eddy, but also from the warmer slope water that drifts westward along the edge of the continent, as appears from the recoveries of Canadian drift bottles. Consequently, the surface water that

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[32] Only a preliminary statement of the general results has yet appeared (Huntsman, 1924); but Doctor Huntsman has very kindly allowed quotation from his unpublished notes.

[33] The account of these experiments contributed in advance of publication by Doctor Huntsman also shows complex drifts inshore and to the eastward for many bottles set out off County Harbor and off Beaver Harbor, which need not be discussed here.

enters the eastern side of the Gulf of Maine in summers of this type is not cold, but actually is warmer than the water it meets within the gulf.

This we found to be the case in July and August of 1914, when salinities and temperatures showed that the cold tongue was eddying offshore toward the edge of the continent, and to the left, a short distance east of the longitude of Cape Sable (Bigelow, 1917), although a dominant southwesterly set of about 1 knot per hour was then recorded in the offing of Shelburne (station 10231). The observations taken during the last week of July, 1915, by the Canadian Fisheries Expedition (Bjerkan, 1919), corroborated by our own September stations for that year (10312, 10313, and 10314), again showed the coldest and least saline water as veering southward from the offing of Shelburne toward La Have Bank — not continuing westward to Cape Sable.

The summer of 1922 seems also to have belonged to this category, because, as Doctor Huntsman informs me, not one of the bottles that were put out to the eastward of Shelburne, Nova Scotia, during that summer has been reported from the Gulf of Maine; but a series set out on a line running southwesterly for 125 miles from Brazil Rock, just east of Cape Sable, on the 17th of that July, evidently coincided with the zone of transition between the Scotian and Gulf of Maine eddies, because about as many bottles from the inner end of the line were reported from the Gulf of Maine and Bay of Fundy (p. 908) as from the eastward, while more either drifted inshore or remained stationary.[34]

Four others, set out near the outer edge of the continental shelf, were picked up on the west coast of Nova Scotia, in the Bay of Fundy, and on the coast of Maine. The latter drifts, Doctor Huntsman points out, indicate a westward tendency along the edge of the continent and entrance into the gulf around or across Browns Bank with the slope water discussed below (p. 842). Such of the bottles from this line as finally drifted into the Gulf of Maine eddy traveled with considerable speed (p. 847); but so many of them worked slowly shoreward, and the dispersal was so nearly equal in the two directions, east and west, that the water off Cape Sable is described by Doctor Huntsman as "a relatively dead zone" at the time, so far as any nontidal drift is concerned. Tidal currents, however, run with great velocity in this region, especially close in to land.

A dead zone of this same sort seems again to have developed off Cape Sable during the summer of 1923, when, as Doctor Huntsman writes, some bottles from a line running eastward from Browns Bank toward La Have Bank (i. e., at right angles to the Cape Sable line of the year previous) were finally recovered in the Gulf of Maine after drifts no more rapid than those of the 1922 series, while others were picked up on the other side of the Atlantic (England, Ireland, France, and the Azores) a year later. The only bottle from lines east of La Have Bank, which is known to have reached the Gulf of Maine during that summer, was one set adrift in Cabot Strait on July 18 and picked up near Cape Sable on December 2. This bottle, Doctor Huntsman suggests, may have gone out along the western side of the Laurentian Channel, then westward along the edge of the continent, and so

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[34] Doctor Huntsman kindly allows quotation of these results in advance of publication. They are discussed more fully in another chapter (p. 908).

finally northward toward the Gulf of Maine, via Browns Bank and the Cape Sable dead water.

In years such as those just described the region in the offing of Cape Sable, out to Browns Bank, between the two major circulatory eddies (Scotian and Gulf of Maine) but not directly within the sweep of either, is evidently the site of a very active mixing of waters of diverse origins. Under such conditions a very abrupt east-west transition in temperature and salinity develops off the cape, proving that the westerly (inshore) component of the Scotian eddy is not the motive power for such water as does then flood into this side of the Gulf of Maine. This eddy, on the contrary, is clearly outlined by the surface salinity for July and August, 1914 (Bigelow, 1917, fig. 18), and for June, 1915, as swinging offshore toward La Have Bank, which prevents it from flooding westward through the Northern Channel, toward which the rotation of the earth would direct it, did the contour of the bottom allow.

The strong tidal currents off southern Nova Scotia must tend, however, to pump water from the Cape Sable deadwater into the gulf, because the flood, running westward at a mean velocity of 1.4 knots (Dawson, 1908, station R; a journey of something like 8½ miles for any given particle of water), must follow westward and northward around Cape Sable as it is forced to the right against the shore by the effect of the earth's rotation. With the ebb similarly deflected to the right, a clockwise movement around the rounded outline of southwestern Nova Scotia naturally results, such as eddies around any submerged shoal in high northern latitudes.

TROPIC WATER

We may next consider the possibility that overflows of the surface stratum of tropical or "Gulf Stream" water, the inner edge of which always lies within a few miles of the edge of the continent, may enter the Gulf of Maine from time to time; also possible movements of the coast water from west to east past Cape Cod into the gulf, either via Vineyard Sound or around Nantucket Island. Water from either of these sources would reach the gulf as warm currents, contrasting with the cold Nova Scotian current, the former high in salinity, the latter low.

As pointed out above (p. 700), events of the first category undoubtedly do occur on occasion. Small amounts of "Gulf Stream" water have long been known to drift inward, toward the sector of coast line bounded on the east by Marthas Vineyard and on the west by Narragansett Bay, during most summers, bringing with them a typically tropical fauna of fishes, planktonic invertebrates, and Gulf weed (Sargassum).

Were it not for the peculiar distribution of densities off the slopes of Georges and Browns Banks, shortly to be described (p. 843), which produce more or less constant dynamic tendency for the surface stratum to move out, seaward, from the edge of the continent (a tendency altered into a long shore current to the westward by the deflective effect of the earth's rotation; p. 846), tropic water might similarly be expected to drive in over the surface right across the banks under the propulsion of high and prolonged southerly winds. Under most conditions, however, the distribution of density imposes an impassible barrier to surface drifts from the southward into the gulf (p. 939). It is fortunate for the fisheries of New England that such is the case, for were Georges and Browns Banks subject to frequent overflows by the high temperatures of the so-called "Gulf Stream" sufficient in amount to dominate the column from surface to bottom, existence on the Banks would become impossible for cod, haddock, halibut, and, in fact, for the whole category of boreal fishes.

Under exceptional conditions departures from the normal temperatures and salinities along the zone of contact of the banks and tropic waters may allow the latter to reach the Gulf of Maine as a surface drift if driven by southerly winds. An overflow of this sort was, in fact, reported by Capt. E. Kinney of the S. S. *Prince Arthur*, who observed unusually blue water with gulf weed and a temperature of 20° C. (68° F.) in the center of the gulf, latitude 42° 43′ N., longitude 69° 13′ W., on July 14, 1911, preceded for several days by a strong current toward the northwest in its western side (U. S. Hydrographic Office pilot chart for January, 1913). However, no events of this sort have come under our observation, so they must be exceptional, for their effects on the salinity of the gulf and on its plankton would be unmistakable.

It may be definitely asserted, therefore, that tropic water from outside the continental edge seldom affects the temperature or salinity of the gulf except as one of the constituents of the water that flows in through the Eastern Channel.

It is one of the most interesting oceanographic features of the Gulf of Maine that the latter is so little subject to tropic influences, either in the physical character of its waters or in its fauna or flora, when tropic water lies so close at hand.

COASTAL WATER FROM THE WEST

The possibility that the coastal water overflows around Cape Cod from the west in any considerable volume, and so into the Gulf of Maine, seems extremely remote. On the contrary, all the evidence of current-meter measurements, drift-bottle experiments, distribution of temperatures and salinities (see especially p. 974), and geographic distribution of the fauna (bottom as well as planktonic) points to just the reverse movement—i. e., out of the gulf in this side. The evidence that the dominant drift past Cape Cod, and so around or over Nantucket Shoals, is out of the Gulf of Maine, not into the latter, is conclusive.

RIVER WATER

In addition to the superficial ocean currents just discussed, which bring water to the Gulf of Maine, its tributary rivers discharge a volume of fresh water so large that it must be taken into consideration in any study of the salinity or circulation of the gulf.

Unfortunately, the annual combined discharge of the several river systems can not yet be stated, much less the contribution made by the numerous minor streams that empty into the gulf, for most of the flow measurements made by the United States Geological Survey within recent years (see especially Porter, 1899; Pressey, 1902; and Barrows, 1907 and 1907a) have been for localities far upstream. The published data for the Kennebec at Waterville, Me., and for the Merrimac at Lawrence, Mass., are perhaps the most instructive in the present connection. These records for the Kennebec cover a drainage area of 4,410 square miles[35] out of a total 6,330—i. e., about two-thirds of the river basin. The average flow is given by Porter (1899) as 6,400 cubic feet per second for the four years 1893 to 1896; and though a great number of records have been obtained subsequently, this figure may be taken as representative. In other words, if this be two-thirds of the total flow of the river (probably it is no more, because two important tributaries enter below Waterville), the Kennebec River annually pours something like 300,000,000,000 cubic feet of water into the Gulf of Maine, or enough to flood an area of about 8,000 square miles[35] to the depth of 1 foot. The discharge from the Merrimac is about the same in relation to the area of its watershed—i. e., an average of about 6,800 cubic feet per second (8 years, 1890 to 1897) from about 4,553 square miles. Flow measurements of the Androscoggin, taken at Rumford Falls, Me., at which point the river receives the run-off from one-half to two-thirds of its total watershed of 3,700 square miles, give a mean of 3,884 cubic feet per second for the years 1893 to 1901, suggesting about 6,400 for the entire watershed of this river. The discharge from the Penobscot, with its larger drainage area (8,500 square miles), averaged about 23,500 cubic feet per second for the years 1899 to 1901 (Pressey, 1902), at White Horse rips, where it drains 7,240 square miles of its total watershed of 8,500, indicating a total run-off of not less than 28,000 cubic feet per second. By a simple arithmetical calcuation the combined discharge from these four rivers alone is sufficient to raise the whole level of the Gulf of Maine, out to its southern rim, by about 1½ feet per year.

This does not include the St. John, the largest tributary of all, with a watershed more extensive than those of the Merrimac, Androscoggin, and Kennebec combined (p. 521), but for which no definite record of its discharge is available; nor of the discharges from the many lesser streams—the Saco, for example, the Presumpscot, the St. Croix, and many smaller. However, the general physical features and vegetation of northern Maine and of such parts of New Brunswick and Nova Scotia as are tributary to the gulf are comparatively uniform, as is the rainfall. Consequently, it is fair to assume that at least as large a proportion of the rain that falls on the watershed of the St. John and of the other unmeasured streams reaches the sea as from the following watersheds where this run-off has actually been measured. The run-off from the St. John watershed may, indeed, be expected to be greater, the rainfall in the interior of New Brunswick being heavier than it is over most of Maine.

River	Locality	Area of watershed, square miles	Period	Annual run-off, depth in inches, for watershed[a]		
				Maximum	Minimum	Mean
Merrimac	Lawrence, Mass	4,452	1907–1917	24.14	13.12	17.29
Androscoggin	Rumford Falls, Me	2,090	1893–1902 1907–1917	28.66	14.28	22.35
Kennebec	Waterville, Me	4,270	1893–1916	32.45	12.73	23.08
Penobscot	West Enfield, Me	6,600	1907–1917	32.06	14.01	25.94
St. Croix	Woodland (Spragues Falls), Me	1,420	1903 1907–1911	30.52	14.96	24.14

[a] The statistics on which this and the following tables are based will be found in Porter (1899), Pressey (1902), Barrows (1907), and in U. S. Geological Survey Water-Supply Papers Nos. 97, 201, 241, 261, 301, 321, 351, 381, 401, 431, 451, and 481.

The run-off from the area tributary to the St. John River may therefore be set at about 24 inches annually. Probably this applies equally to the Nova Scotian streams, while the run-off for the minor rivers along the west and north coasts of the gulf may be estimated at 18 to 22 inches—an average of not less than 18 to 24 inches for the whole watershed of the gulf.

It is not wise to estimate more precisely from data of this sort, because longer terms of observation or a multiplication of recording stations might alter the results; but the ratio that has now been established between the rainfall and the annual run-off at several observing stations confirms this calculation. Thus, Barrows (1907a, p. 110) found the run-off from the Androscoggin basin to range from 22 to 67 per cent of the rainfall over the period 1893 to 1905, averaging 59 per cent. During the same period, the run-off from the Cobbosseecontee, one of the chief tributaries of the Androscoggin, averaged 44 per cent of the rainfall (Pressey, 1902, p. 70). The average for the Presumpscott basin for 1887 to 1901 was 46 per cent of the rainfall (Pressey, 1902, p. 104), and data for the four-year period, 1914 to 1917, showed that 50 per cent of the rain that fell on the Merrimac watershed ran off via that river.

The average amount of fresh water reaching the gulf via the chief rivers tributary to it may therefore be set at about 50 per cent of the annual precipitation over its watershed, which ranges from about 38 to about 50 inches.

Assuming a yearly run-off of about 20 inches from the 61,000 square miles of watershed, this is sufficient to form a layer some 31 inches thick over the entire gulf, out to its southern rim, illustrating more concretely the relationship which this vast run-off of river water bears to the area of sea into which it is discharged. If the yearly amount by which rain and snow falling on the gulf exceeds the evaporation from its surface be something over 1 foot (p. 841), the total yearly influx of fresh water is sufficient to raise the level out to Georges Bank by at least 43 inches, or almost ⅔ of a fathom.

The seasonal distribution of this contribution of fresh water has an important bearing on the seasonal fluctuations of the salinity of the gulf (p. 701), hence demands notice here. As every New Englander knows, our rivers are in flood in spring, of which the Kennebec may serve as an illustration, both because records of its daily discharges have been kept for many years (Barrows, 1907) and because its situation and the general topography of its watershed make it typical of the rivers of Maine and New Brunswick. The following table for the 10-year period, 1893 to 1902, is compiled from Barrow's (1907) records.

Mean discharge of Kennebec River at Waterville, Me.

Month	Run-off, cubic feet per second	Run-off, in inches	Month	Run-off, cubic feet per second	Run-off, in inches
January	2,919	0.76	August	3,811	1.03
February	3,357	.82	September	2,893	.75
March	8,454	2.28	October	3,011	.82
April	24,811	6.49	November	4,685	1.23
May	20,032	5.40	December	3,944	1.17
June	10,031	2.62			
July	6,116	1.65	Monthly mean	7,838	2.10

Two-thirds of the total run-off for the year thus falls during the three spring months, and more than half of it during April and May. This does not exactly represent the natural condition, because the Kennebec is more or less controlled by the several dams; but water-power developments have not been sufficient to mask its spring freshets—still less have they on the Penobscot or the St. John Rivers. Hence, the seasonal fluctuations in the flow of the Kennebec may be taken as generally representative of all the considerable streams that empty into the gulf north and east of Cape Elizabeth and of the Saco as well.

Originally the Merrimac, also, came into flood in the spring, at the season when the snow blanket melts and the ice goes out; but it is now so largely harnessed for industrial purposes that its seasonal flow no longer shows as pronounced a freshet in April and May as New England waterways do in their natural state. Its largest run-off still falls in April, however, and its smallest in September, as appears from the following table:

Merrimac River at Lawrence, Mass., for the period 1907 to 1916

Month	Run-off, in inches	Month	Run-off, in inches
January	1.3	August	0.8
February	1.2	September	.6
March	2.7	October	.8
April	3.6	November	1.0
May	2.3	December	1.1
June	1.3		
July	.8	Monthly average	1.4

Automatic tide gauges, which have been in operation at a number of points around the coastline of the gulf between Cape Cod and the Bay of Fundy, have shown the sea 0.1 to 0.2 feet lower than the mean in the latter part of winter, and about this same amount higher than the mean toward the end of the summer.[36] This variation probably reflects the seasonal variation in the inflow of land water.

RAINFALL AND EVAPORATION

Although land drainage is the chief source for fresh water for the gulf, rainfall also adds a considerable increment. No record of the precipitation over the offshore parts of the gulf itself is available, but the monthly and annual averages for four representative coast stations—Boston, Portland, Eastport, and Yarmouth—tabulated below suggest an annual fall of 40 to 45 inches for the gulf as a whole.

Average rainfall, in inches

Month	Boston	Portland	Eastport	Yarmouth	Month	Boston	Portland	Eastport	Yarmouth
January	3.82	3.81	3.84	5.16	August	4.03	3.57	3.26	3.62
February	3.44	3.65	3.62	4.17	September	3.19	3.20	2.97	3.61
March	4.08	3.75	4.28	5.00	October	3.86	3.66	3.85	4.12
April	3.60	3.11	2.94	3.82	November	4.10	3.80	4.08	4.49
May	3.55	3.67	3.80	3.57	December	3.41	3.68	3.97	4.77
June	3.03	3.36	3.24	2.93					
July	3.36	3.25	3.42	3.47	Total	43.40	42.50	43.30	48.73

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[36] Information contributed by U. S. Coast and Geodetic Survey.

Evaporation, of course, partially offsets precipitation. Unfortunately, no data are available on this subject from any localities that might be supposed to approximate conditions as they prevail at sea in the Gulf of Maine; the outer islands, for example, would be such. Nevertheless, there is no reason to suppose that evaporation at sea is greater than on land, especially when the sea is blanketed with thick fog, as the northern and northeastern parts of the gulf and its offshore banks often are during the summer season. The following records of evaporation for Maine, Massachusetts, and Nova Scotia may therefore be taken as the maximum. The average monthly evaporation from a free water surface at three stations in Maine in the basins of the Penobscot, Kennebec, and Androscoggin Rivers is given by Barrows (1907a, p. 114) as follows, in inches:

Month	Average evaporation, in inches	Month	Average evaporation, in inches
March	2.23	July	5.28
April	3.48	August	5.12
May	1.90	September	3.00
June	2.87	October	2.33

No data are available for the winter months, when the observations were necessarily made from a frozen surface, but it may be assumed that evaporation takes place no more rapidly from open water from November through February than in October or March—say at the rate of about 2.2 inches monthly. This suggests a total evaporation for the year of about 35 inches of fresh water.[37] According to FitzGerald (1886), the annual evaporation is somewhat larger near Boston (about 39 inches), as might be expected.

Data supplied by the United States Weather Bureau for Yarmouth, Nova Scotia, more closely paralleling conditions over the gulf because of the greater frequence there of onshore winds, show the following monthly averages over a period of 13 years:

Evaporation at Yarmouth, Nova Scotia

Month	Average evaporation, in inches	Month	Average evaporation, in inches
April[1]	1.08	August	3.55
May	3.04	September	3.57
June	3.49	October	1.59
July	3.94		

[1] 1920 only; ice in the tank on several days.

Assuming an average evaporation of 1.5 to 2 inches monthly, for the period November to March, the annual evaporation of fresh water at Yarmouth would be close to 29 inches from a surface of open (not frozen) water; the average for the Gulf of Maine is probably not more than 30 inches. These measurements are for fresh

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[37] These measurements were taken freely exposed to the sky (Barrows, 1907a, p. 114, pl. 21).

water, however, which evaporates somewhat more rapidly than salt water under equal conditions of temperature, humidity, etc. According to Mazelle (1898), the evaporation of salt water averages about 81 per cent that of fresh at Trieste, while Okada (1903) found it averaging about 95 per cent that of fresh over a 7-year period in Japan. As Okada's measurements were taken open to the sky, Mazelle's under a roof, the former simulate more the conditions at sea.[38]

As a rough approximation, the evaporation of salt water from the surface of the Gulf of Maine may, then, be set at about 27 to 28 inches, or about 71 centimeters, annually.

DEEP STRATUM

SLOPE WATER

The scources so far mentioned contribute chiefly to the superficial stratum of the Gulf of Maine. We must next consider the comparatively warm and highly saline water that drifts intermittently inward along the trough of the Eastern Channel to form the bottom water of the gulf. The high salinity of this makes its offshore origin clear enough. As certainly, however, it is *not* a direct and unmixed indraft from the mid depths of the Atlantic Basin. Two reasons warrant this confident assertion. In the first place, neither the temperature nor the salinity of the bottom water of the Eastern Channel, or of the gulf basin within, is high enough to accord with such an origin. In the second place, profiles enough have now been run by various expeditions to make it certain that a broad band, intermediate in temperature and in salinity between the coastal water, on the one hand, and the tropic Atlantic water, on the other, always separates the latter from the edge of the continent from Georges Bank to the Grand Banks.

The "cold wall" of the earlier oceanographers—the source of this band—has been the subject of much discussion, with upwelling from the ocean abyss and currents from the north most freqently invoked to explain its low temperature as contrasted with the "Gulf Stream" on its seaward side. Recent explorations, however, have made it clear that this "cold wall" is simply the product of the mixture that is constantly taking place between the tropic water, on the one hand, and the coastal water, on the other (or Arctic water in the Grand Banks region), at their zone of contact along the slope of the continent. "Slope water," as defined by Huntsman (1924), is therefore a better name for it than "cold wall," and as such it is referred to repeatedly in the preceding pages.

It is the presence of a continuous zone of this slope water right across the mouth of the gulf at all times of year which effectively bars unadulterated oceanic or tropic water from entering the Eastern Channel. It is because the most saline bottom water of the gulf draws from this source that members of the bathypelagic plankton of the Atlantic Basin occur only as the rarest of stragglers within the gulf (Bigelow, 1926, p. 67).

Explorations by the Canadian Fisheries Expedition (Bjerkan, 1919; Sandström, 1919; and Huntsman, 1924) have similarly proven that the high salinity (34.5 to 34.7 per mille) and comparatively high temperature (4° to 5°) of the deepest stratum

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[38] For further discussion of evaporation see Krümmel, 1907, p. 244.

of the Gulf of St. Lawrence are similarly maintained by an inflowing bottom current of the same slope origin.

The motive power that brings water of this character to the Gulf of Maine as a bottom current through the Eastern Channel (intermittently, it is true, but regularly enough to maintain the comparatively constant salinity and temperature actually recorded) is to be sought in the distribution of density along the edge of the continent. A considerable body of evidence has now been accumulated to the effect that the zone of contact along which coast and ocean waters mix, and where the slope water is manufactured, averages somewhat more dense (heavier) than the water in on the edge of the continent, except right at the surface. All the profiles that have been run out across the continental edge off Nova Scotia in summer, both those by the Canadian Fisheries Expedition (Sandström, 1919, pl. 9, sections 13, 14, 15, 16, and 17) and by the United States Bureau of Fisheries, have shown something of this sort. Thus, on July 25 to 28, 1914, on the first *Grampus* profile out from Shelburne (stations 10231, 10232, and 10233), the stratum between the 20-meter and 150-meter levels was more dense just outside the edge of the shelf than in over the latter, though the surface was less so.

The *Grampus* again found the water heavier over the continental slope (station 10295) than in over the shelf (fig. 168) along this same profile on June 23 and 24, 1915, with a decidedly steep density gradient at the 50 to 100 meter level. Consequently, the whole mass of water on the shelf above 100 meters must have had a hydrostatic tendency to drift seaward, except immediately at the surface.

A March profile along this same general line (stations 20073 to 20077) again shows higher densities at the outermost station, at 100 to 220 meters, than along the edge of the continent (fig. 169)—evidence of this same dynamic tendency for the water of low salinity and temperature to move out across the slope, though at the inshore end of the profile the dynamic tendency in the superficial stratum was the reverse.

The water at 20 to 120 meters' depth was likewise somewhat more dense over the southeastern slope of Georges Bank (station 10220) than in on the neighboring edge of the latter (stations 10221 and 10225) in July, 1914; again in April, 1920 (stations 20109 to 20111), though our corresponding profile for March, 1920, crossed a more complex alternative of heavier and lighter bands there (stations 20065 to 20069).

The cross section of the western end of Georges Bank for July 20 and 21, 1914 (fig. 170), is especially instructive in this connection, being the only one of our profiles that has reached water of oceanic salinity (36 per mille). Here, again, the upper 50 meters of water proved slightly more dense at the outer end (station 10218) than over the neighboring edge of the bank (station 10216), resulting in a comparatively steep south-north gradient of density, though the relationship was just the reverse at a depth of 70 to 140 meters. A slight differential of this same order (density higher at the outermost stations than in on the bank) also prevailed in this same general region in February and again in May of 1920 (stations 20045 and 20046 for February; 20128 and 20129 for May); but in the cold July of 1916 this seems to have applied only at depths greater than

40 meters, with the surface water more dense over the bank (station 10348) than over its seaward slope (stations 10349 and 10352), though some doubt exists as to the salinity (hence as to the density) at the critical station (10349, p. 992).

Thus, densities rule lower along the outer edge of the offshore banks, abreast of the Gulf of Maine and off Nova Scotia to the eastward, than along the continental slope that bounds the banks on the offshore side. The relationship at any given date may be of the reverse order, either close to the surface as in July, 1916, or along the 100-meter contour, as in July, 1914. However, we have never failed to find the surfaces of equal density rising comparatively steeply from the outer part of the shelf through the greater part of the depth zone there included, out across the edge of the continent between the longitudes of Shelburne, Nova Scotia, and of Cape Cod.

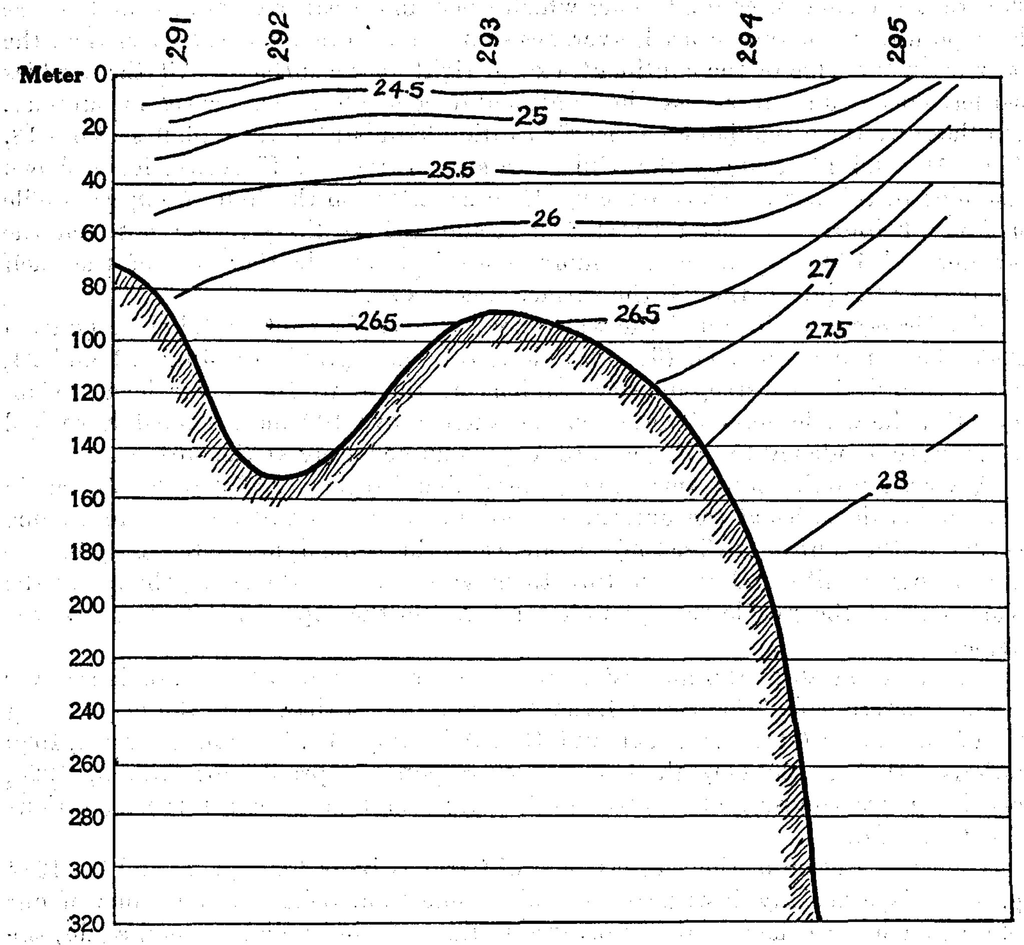

FIG. 168.—Density profile crossing the continental shelf in the offing of Shelburne, Nova Scotia, June 23 to 24, 1915. Corrected for compression

To the east and north of our limits, and especially off the Newfoundland Banks, this zone of mixture is not only heavier than the coast water on its inner side (or

Arctic water, according to locality), but often, if not always, heavier than the tropic water on the outer side as well (Witte, 1910; E. H. Smith, 1924, p. 140, 1925, figs. 10, 12, and 19), causing the dynamic tendency for surface water to move in from both sides toward this heavy zone (or "cabelling"), which seems first to have been emphasized by Witte (1910). Huntsman, too (1924, p. 278), definitely accepts "cabelling" as a governing event in the formation of the slope water; and although more recent hydrodynamic studies (see especially E. H. Smith, 1926) have made it clear that actual sinking is usually prevented there by the effect of the earth's rotation, a potential sinking zone of this sort does nevertheless tend to draw in surface water from both sides toward the zone where the surfaces of equal density depart most from the horizontal, and so to set up a horizontal circulation.

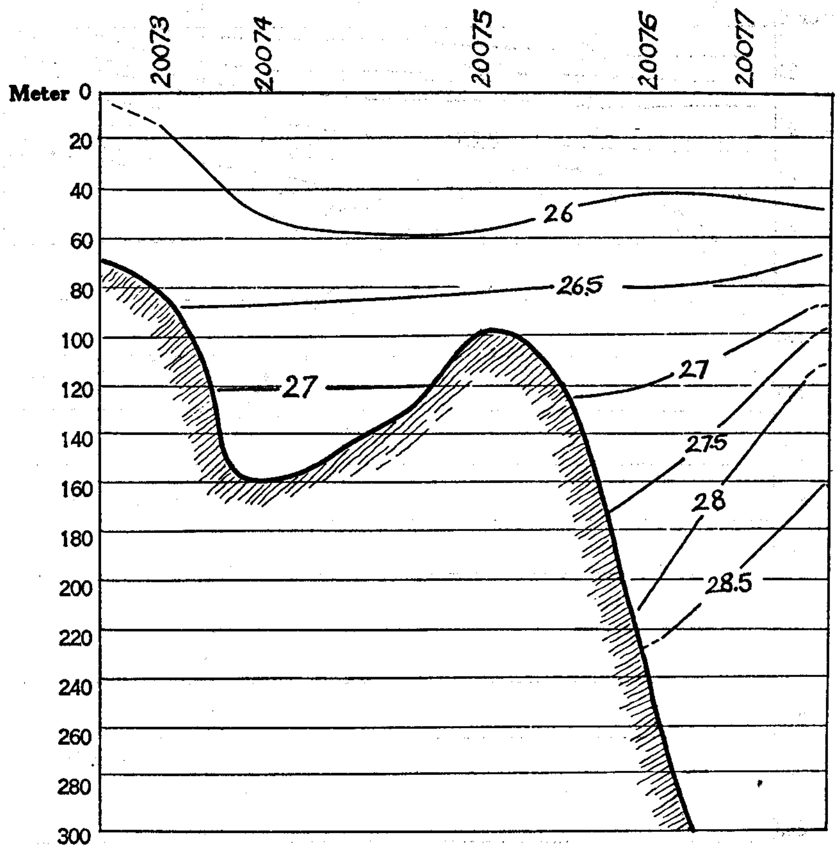

FIG. 169.—Density profile crossing the continental shelf in the offing of Shelburne, Nova Scotia, March 17 to 20, 1920. Corrected for compression

A potential sinking zone of this same sort was revealed by one profile run off La Have Bank by the Canadian Fisheries Expedition in July, 1915, when the upper 100 meters proved more dense just outside the edge of the continent (Bjerkan, 1919, *Acadia* stations 41 to 43) than in on the edge of the shelf, on the one hand (*Acadia* stations 39 and 40), or at the outermost station, on the other (*Acadia* station 44).[39] It is doubtful how regularly profiles abreast of the gulf or off southern New England would show this decrease in density seaward from the continental slope.

In the preceding discussion I have taken pains to speak always of a "dynamic tendency" toward movements of the water, never of such movements as taking place; because in our latitudes the currents that actually follow inequalities of density of this sort are given quite different characters by the deflection resulting from the rotation of the earth, by which the apparent track of any current (or other body moving freely over the earth) in the Northern Hemisphere is deflected to the right.[40]

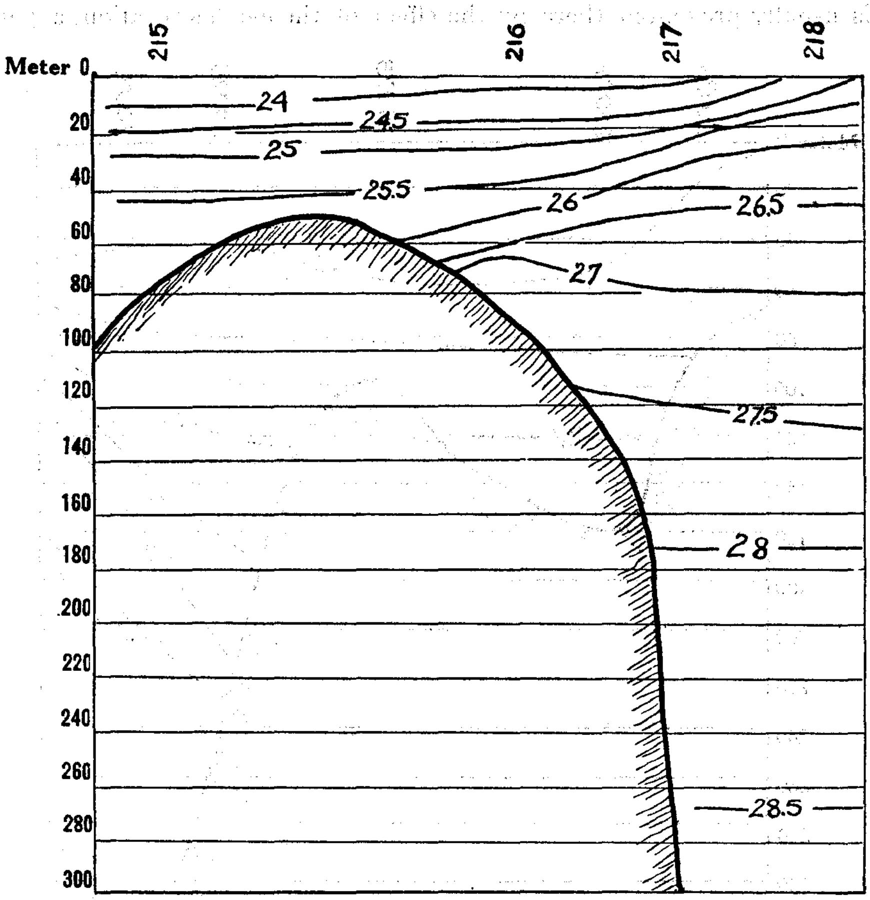

FIG. 170.—Density along a cross profile of the western part of Georges Bank, July 20 and 21, 1914 (stations 10215 to 10218). Corrected for compression

The rôle that this quasi-force plays in directing the ocean currents, however set in motion, is now so generally appreciated that no discussion of it is called for here.

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[39] None of our *Grampus* or *Albatross* profiles have run out far enough to show this relationship, if it existed.

[40] Krümmel (1911, p. 449) and Sandström (1919) have given perhaps the simplest statements of this subject, in its oceanographic bearing, and discussions of the effects of the centrifugal force resulting from the earth's rotation in relation to the ellipsoid form of the earth. See also Ferrell (1911), Davis (1885 and 1904), and Bjerknes (1910 and 1911).

Baldly stated, its practical effect on the slope water which dynamic forces tend to drive out to sea from the continental slope, as described above (p. 843), is to swing this drift to the right (i. e., to the west), thus altering into a longshore current what otherwise would be (and potentially is) an offshore set.[41]

In this way a dominant drift from east to west tends to develop along the upper part of the continental slope of La Have and Browns Banks so long as the distribution of density is of the type actually recorded on the *Acadia*, *Albatross*, and *Grampus* cross profiles of this part of the continental shelf for March, 1920, June and July, 1915, and July, 1914. On each of these occasions the dynamic tendency, acting as the propulsion for such a drift, involved the whole mass of bottom water from the crest of La Have Bank down the slope to a depth of at least 200, if not 250, meters. An east–west drift of the bottom water seems, then, comparatively constant on just this part of the slope.

In July, 1915, this drift involved the whole column of water, surface to bottom; again, in July, 1922, when bottles set out near the edge of the shelf in the offing of Cape Sable drifted into the Gulf of Maine (p. 908). Sandström's (1919) calculation of a surface current of about 5 miles per day[42] toward the southwest, along the outer part of the shelf, on this line (between *Acadia* stations 39 and 41), shows that the surface water may travel with considerable velocity at times when the whole column is involved in this westerly set along the edge of the continent. This is confirmed by the drifts of four bottles set out 48 to 60 miles off Cape Sable in July, 1922, three of which went to the Bay of Fundy at minimum rates of 3 to 4 miles per day, and one to Winter Harbor, near Mount Desert, at a daily rate of at least 2 miles, and probably considerably faster than that (p. 908). However, the obliquity of the surfaces of equal density, which originates this drift, decreased with increasing depth on the *Acadia* section, so that Sandström's (1919, p. 332) table indicates a mean velocity of only about 1 mile per day for the whole column of water, surface to bottom, between the critical stations (from No. 40 out to the 200-meter contour), with the bottom water creeping westward not faster than about one-half mile per day[43] at a depth of 100 to 200 meters.

The outermost bottle (which is known to have gone to the Gulf of Maine from the line put out off Cape Sable by the Biological Board of Canada in 1922) was set adrift over the 200-meter contour[44] 59 miles out from the land, the only returns from bottles set adrift farther out coming from Europe. This limitation of the westerly drift to a narrow belt corroborates the *Acadia* profile of July, 1915, on which it was only about 20 miles wide (and similarly located), giving place farther out to a succession of lighter and heavier bands, indicating a stronger but even narrower countercurrent to the eastward; then, outside of that, a second line of drift to the westward.[45]

Evidently an active mixing of cold and warm waters was taking place at the outer end of this profile at the time, with bands of higher and lower temperature

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[41] See Smith's (1926) exposition of this important concept.

[42] The velocity arrived at by Sandström (1919) from hydrodynamic calculation are only *relative* to the most nearly stationary stratum of water, not absolute. This does not lessen their significance in the present case, for with the whole column moving in the same direction the actual velocities would be somewhat greater than the calculated.

[43] About 1.4 centimeters per second, or 0.025 knot per hour.

[44] Information contributed by Doctor Huntsman.

[45] See Sandström (1919, pl. 15) for the calculated velocities of these two lines of drift.

eddying in the extremely complex fashion that may be expected to characterize the zone of contact between waters that differ widely in their physical character and in their direction of flow.

Similar alternations between colder (and less saline) and warmer (and more saline) bands have been reported on several occasions and at localities widely separated off the eastern seaboard of North America; but in most cases, at any rate, these are transitory and rapidly changing phenomena. The westward drift of water close in to the upper part of the slope, just described, has, on the contrary, proved characteristic of the La Have Bank region; and so long as the dynamic motive for this drift persists, the neighboring oceanic triangle off the mouth of the Eastern Channel is supplied with slope water from the eastward. By this reasoning, the current that flows into the bottom of the gulf via the Eastern Channel draws from the slope water manufactured at about an equal depth on the Nova Scotian slope—chiefly between Browns and La Have Banks—not from shoaler or deeper strata there.

This conclusion is confirmed by the fact that temperature and salinity proved very nearly the same on bottom in the channel (34.7 to 35 per mille and 6° to 7° at 200 to 250 meters) as at equal depths on the slope between these two banks (34.6 to 34.9 per mille and about 7° to 8°) in July, 1914, in June, 1915, and again in the spring of 1920.[46]

Further evidence that the indraft into the channel is supplied from the eastward, not from the westward, is afforded by the fact that considerably lower temperatures and salinities have been recorded around the eastern and southeastern slopes of Georges Bank (p. 714). In fact, there is reason to believe that the western side of the channel is the site of a dominant drift outward from the gulf (p. 974).

The cold band encountered off the southwest slope of Georges Bank by the *Grampus* in July, 1916, and reported there in other summers (pp. 608, 919) may also be credited with an eastern source, because its temperature and its salinity both agree closely with that of the slope water that is manufactured in the offing of Cape Sable in early summer, as exemplified by the observations taken there in June, 1915, and July, 1914 (p. 629; Bigelow, 1922, p. 166). Thus it owes its low temperature indirectly to the Nova Scotian current (and so to ice melting far to the eastward).

Why this southwesterly cold current was so much more in evidence along the bank in 1916 than in 1889, 1913, or 1914 remains an open question, but it seems probable that some westerly movement of slope water takes place along Georges Bank to a greater or less extent every spring as the Nova Scotian current floods to its maximum velocity and volume. In some years (1889, for instance, and 1916) this drift persists into the summer, as seems to have been the state in 1922, also, when so many of the bottles set out at the edge of the continental shelf in July made long drifts to the westward (p. 882). In other years (exemplified by 1914) it seems to be obliterated west of longitude about 68° by July, as the tropic water advances toward the edge of the continent. But although so variable, the existence of this cool band in some summers is extremely instructive as one of the several

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[46] The slope water was somewhat more saline at this locality at the end of July, 1915 (Bjerkan, 1919, *Acadia* station 41), but no observations were taken in the channel at the time.

evidences of the general tendency of the slope water to move westward from the Nova Scotian slope.

The slope water, moving westward, is forced against Browns Bank by the earth's rotation. Consequently, with the Eastern Channel offering an open route for it to the right, it is reasonable to think of a screwing motion as taking place into the latter around the southerly and southwesterly slopes of Browns Bank so long as the propulsive dynamic force resulting from regional inequalities of density persists over the Nova Scotian slope to the eastward.

Additional evidence that the bottom water does actually move inward through the Eastern Channel is afforded by the inequalities of density within the basin of the gulf, where the surfaces of equal density (approximately horizontal in the upper 50 to 60 meters) show a considerable slope from the channel inward at depths greater than 80 to 100 meters.

This density gradient in the deep water may be illustrated most graphically by charting the depth to which it is necessary to sink in order to reach water of a given value, choosing 1.027 as the most illustrative (figs. 171 and 172). The precise upper contour of this mass of heavy bottom water has varied from month to month, as might be expected. Thus, in June, 1915, the slope was steepest near the entrance to the channel, with the surfaces of equal density lying nearly horizontal thence inward along the western arm of the basin. In July and August of 1914 the the most abrupt slope, involving the whole column of water deeper than 50 meters (fig. 171), was situated farther within the basin. A density gradient of the same sort was again recorded in the eastern part of the basin in March, 1920, and a weaker contrast (but one of the same order) between the channel, on the one hand, and the inner parts of the basin, on the other, in April of that year, sufficient to show it a permanent characteristic of the gulf.

The implication of a density gradient of this sort is obvious. Only by the introduction of heavy water into the gulf via the channel could it be maintained against the action of the hydrostatic forces that are constantly tending to make horizontal the surfaces of equal density.

The inflowing bottom current, which maintains the high salinity (34.5 to 35 per mille) of the deeps of the gulf, thus corresponds, both in cause and in effect, to the indraft of offshore water that has been recorded in many an estuary. The gulf, in fact, is nearly as estuarine in this respect as it would be if the offshore banks (Georges and Browns) were above water, and so actually inclosed it except for the deep channels between.

In the preceeding discussion I have spoken as though this inflowing current and the gradients of density that give rise to it were comparatively constant. Actually, however, our observations on temperatures and salinity have revealed considerable fluctuations in the volume of water that enters the gulf via this route at various seasons and in various years.

It goes almost without saying that no sharp distinction can be drawn in salinity between waters of different origins, especially where the water is stirred as actively as it is in the Gulf of Maine; but the isohaline for 34 per mille may be taken as roughly outlining the "slope water" that has recently entered the gulf or that has continued little altered during its sojourn there, if the product of an earlier invasion.

So far as our records go, slope water of this high salinity reaches its widest expansion within the gulf in April (p. 737). The indraft through the channel, however, seems to slacken during that month, for the bottom layer of 34 per mille water was much thinner in May[47] of 1915 than in March or April of 1920 (p. 754), and the area occupied by it was much less extensive. In that year (probably a representative one) but little water can have moved inward through the Eastern Channel during

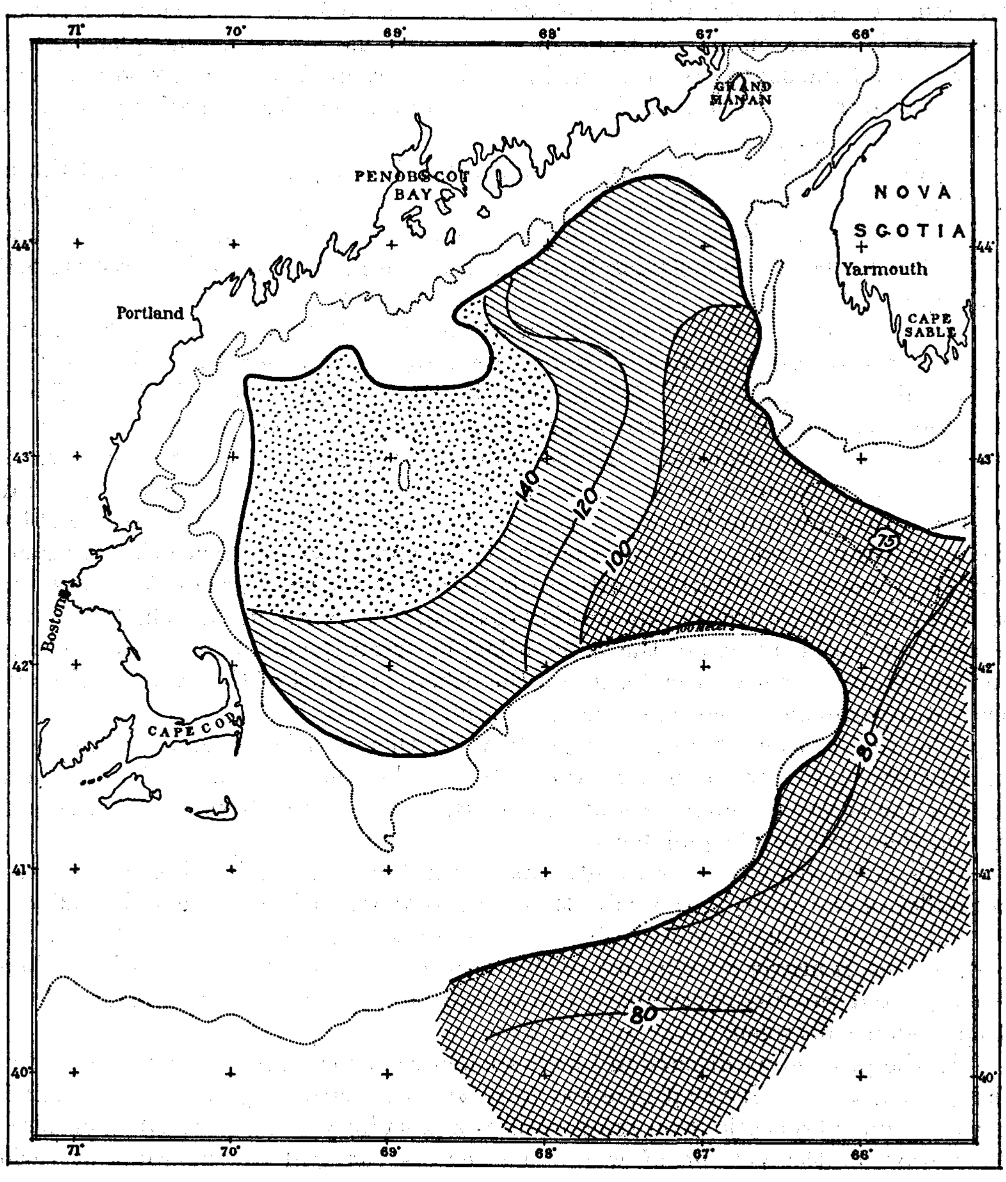

FIG. 171.—Depth of the density surface (isopycnobath) for 1.027; July and August, 1914. Corrected for compression

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[47] In May, 1915, the bottom water of the western arm of the basin was more saline than 34 per mille; that of the eastern less so

May or the first half of June, for salinities as high as 34.5 to 35 per mille were confined to the channel and to the neighboring part of the basin during the last half of that month, with bottom values of 33.8 to 33.9 per mille in the inner branches of the latter—western as well as eastern. A considerable indraft of slope water certainly took place shortly thereafter, however, spreading inward over both arms of the basin, where the salinity of the bottom water had again risen above 34 per mille by the end of the summer in a layer of considerable thickness (p. 786).

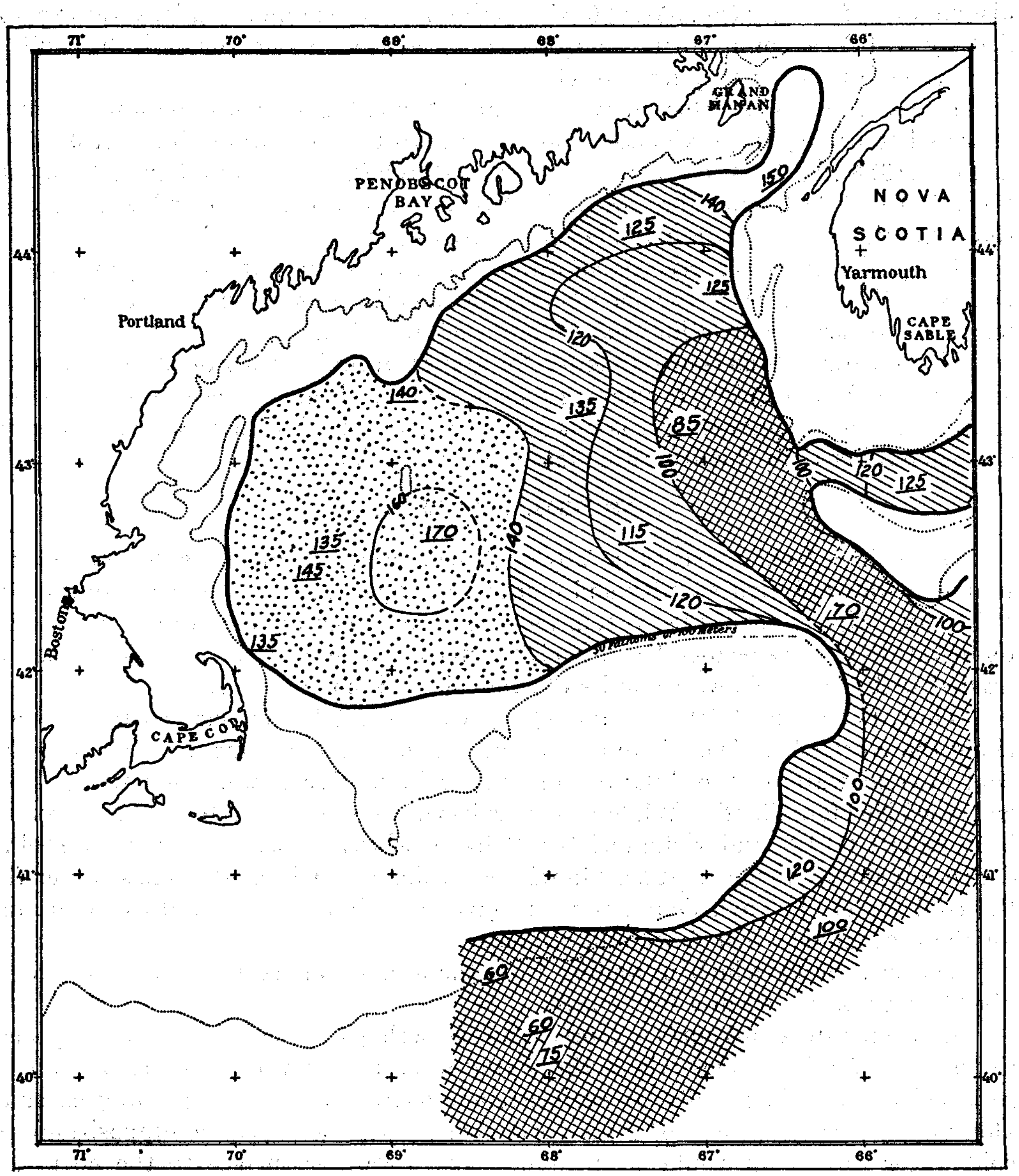

FIG. 172.—Depth of the density surface (isopycnobath) for 1.027; March, 1920. Corrected for compression

With 10 of our 14 August stations as deep as 180 meters (100 fathoms), or deeper, also showing bottom values higher than 34 per mille in 1912, 1913, and 1914, this indraft is evidently characteristic of June or July. No doubt, however, it varies from year to year, both in its seasonal schedule and in its volume and velocity, and the distribution of density (pp. 958, 960) shows that in some summers, at least (as exemplified by 1914), a counterdrift develops through the channel, out of the gulf, in July, though perhaps only for a brief period.

In a summer when this inflowing bottom current is active, slope water may be expected to occupy approximately the area shown in the contour chart for July and August, 1914 (fig. 152), its boundaries, as in March less extensive than in April, 1920 (figs. 100 and 118), including only the two arms of the trough and the region of their junction instead of the whole central part of the gulf basin.

By good fortune our records afford charts of the slope water at its maximum for the respective months[48]—the one representing a period of active inflow, the other the tendency toward equalization that follows such a period.

Slope water is thus shown to enter the gulf from midsummer on through autumn and winter—but certainly in varying pulses—and to slacken or cease during the late spring and early summer. It is not possible to outline its fluctuations in the gulf more definitely than this from the data gathered so far.

ABYSSAL UPWELLINGS

Upwellings from the oceanic abyss, if such occur, would be a second possible source of water of high salinity and moderate temperature for the deeps of the Gulf of Maine. Upwelling of this sort, in fact, has often been invoked to explain the low temperature of the so-called "cold wall" (referred to here as "slope water"), as contrasted with the tropic water on its offshore side (Buchan, 1896).

Thus, Pettersson (1907 and 1907a), for example, definitely classed the cold wall along the North American littoral as an updrift over the continental slope from the cold abyssal water of the Atlantic, having for its motive power the sinking of cold water off Newfoundland. While this view has not found a very favorable reception, both Schott (1912) and Krümmel (1911) have believed that more or less upwelling does occur along our coasts, at least in winter; while A. H. Clark (1914) has argued that the cold water off Nova Scotia must receive something from the abyss to account for the geographical distribution of crinoids.

The criteria by which upwelling from the oceanic abyss would be made recognizable may be stated in a few words.

In temperate zones surface temperature is perhaps the best index of this process in summer, for in regions where the water wells up actively seasonal warming is retarded, causing abnormally low surface temperature. Unless the upwelling extended along the whole east coast of North America (a most improbable supposition) any cold water welling up would be surrounded by a warmer surface to the north and south of it as well as on its offshore side, as is the case off California (McEwen, 1912) and off the northwest coast of Africa (Schott, 1902, pl. 8). At the same time there would be a continuity in salinity between this cold water near the surface and the

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[48] 1920 was a salt March, compared with 1921; 1914 a salt summer, compared with 1913.

deep stratum that served as the source for the updraft, as demonstrated by the distribution of salinity off the coast of Morocco (Schott, 1912, pl. 33). Off the northeastern American seaboard abyssal water would also be betrayed by its precise combination of salinity and temperature, for while only moderately cold (about 4°), the salinity of the Atlantic abyss is much higher (34.9 to 35 per mille) than that of any water on the continental shelf of like temperature.

The observations taken in 1912, on our first cruise, were enough to prove that the inner part of the Gulf of Maine received little if anything from this abyssal source, its salinity being too low and its mean temperature too high.

The rapid warming of the superficial stratum, which takes place all along our seaboard in spring from Nova Scotia to Chesapeake Bay (except in limited areas of active tidal stirring), is, of itself, incompatible with any widespread upwelling of abyssal water, unless this be confined to the deeper strata. So, also, is the wide variation in surface temperature from season to season; for any considerable updraft from the abyss would necessarily check vernal warming and so narrow the seasonal range of temperature. The profiles which the *Grampus*, *Acadia* (Bjerkan, 1919), and *Albatross* have run across the continental shelf between Chesapeake Bay and the Laurentian Channel have produced a large body of evidence to the same general effect; particularly welcome because upwelling had been postulated more on theoretic grounds than from first-hand observation, previous knowledge of subsurface salinity on the continental shelf between Cape Sable and Chesapeake Bay being virtually *nil*. None of these temperature profiles for the summers of 1913, 1914, 1915, and 1916 (Bigelow, 1915 to 1922) yield any evidence that abyssal water ever tends up the slope, much less reaches the continental shelf at that season. To the west of Cape Sable, in fact, the coldest water in on the shelf has been separated from the low temperatures of the water of the deeps by a somewhat warmer zone washing the edge of the continent bottom at intermediate depths in most cases (p. 617). The corresponding salinities have been no more compatible with upwelling either at the time of observation or shortly previous, the coldest water on the shelf being in every case much less saline (below 33.5 per mille) than the level of equally low temperature outside the edge of the continent (34.9 per mille, or higher, at all seasons).

As I have discussed this question in detail in earlier publications (1915, p. 258; 1922, p. 166), I need only add here that none of the observations taken by the *Bache* off Chesapeake Bay in January, 1914 (Bigelow, 1917a), by the *Grampus* between Marthas Vineyard and Chesapeake Bay in November, 1916 (Bigelow, 1922), or by the *Albatross* off the Gulf of Maine in the spring of 1920, show any more evidence of abyssal water reaching the continental shelf than did the earlier observations.

The only route we need consider, then, by which abyssal water might, perhaps, enter the Gulf of Maine, is the Eastern Channel; but the precise combination of temperatures and salinities recorded in its trough for the months of March, April, June, and July (6.07° to 7.2° and 34.6 to 35.03 per mille), combined with the general distribution of salinity and temperature within the gulf, points to quite a different source (the slope water) for the intermittent current that drifts inward over the bottom of the channel, as is discussed above (p. 842).

The distribution of density must, in fact, strongly resist any force, such as offshore winds driving the surface water out to sea, which would tend to draw abyssal water upward over the continental slope abreast the Gulf of Maine; for in every case we have found a decidedly stable state of equilibrium prevailing there. In fact, most of our cross sections of the outer part of the continental shelf abreast the gulf and to the eastward show a general dynamic tendency of quite a different sort—namely, one leading to the development of a drift of the inner slope water toward the west (p. 847), while a counter drift of the outer slope water (or "inner edge of the Gulf Stream") toward the east has often been recorded.

In short, continued observation has not adduced any evidence that water from the ocean deeps ever wells far enough up the continental slope to reach the Eastern Channel, much less to overflow the offshore rim of the gulf.

This conclusion does not imply that upwelling may not take place over the lower part of the continental slope from the Atlantic abyss. On the contrary, much evidence has accumulated to the effect that some such process is of wide occurrence along the lower part of the slope, below, say, the 500 to 1,000 meter level, westward and southward from Georges Bank. Perhaps the clearest evidence of this is afforded by a profile run from Chesapeake Bay to Bermuda by the *Bache* in January and February, 1914, when the uniform abyssal water (about 4° in temperature and 34.9 to 35 per mille in salinity) was banked up against the slope to within 1,100 to 1,200 meters (Bigelow, 1917a, figs. 11 and 12). This also appears on a profile run by the *Dana* from Bermuda to Norfolk, Va., in May, 1922 (Nielsen, 1925, fig. 4). But no direct evidence has yet come to hand that water from this deep source ever reaches the continental shelf of eastern North America in volume sufficient to affect the temperature or salinity of the coast waters.[49]

In denying the occurrence of abyssal upwelling as a cause of low temperature in the Gulf of Maine, I do not refer to upwelling from shallow water along shore—a common event, which often exerts an immediate effect on the temperature and salinity of the surface water in the vicinity in spring and summer, as described in an earlier chapter (p. 550).

RECAPITULATION

The Gulf of Maine incloses a sector of the typical coastwise water of the northwestern Atlantic, receiving its most important accessions periodically from the following sources: Slope water of high salinity (close to 35 per mille) and close to 6°–8° in temperature flows intermittently into the gulf as a bottom current, as it does also into the Gulf of St. Lawrence and into other smaller depressions on the continental shelf. There is strong evidence that the slope water that reaches the Gulf of Maine has its source along the Nova Scotian slope to the eastward. The cold Nova Scotian current brings a large volume of water of low salinity into the gulf from the eastward, past Cape Sable, in spring, as a surface drift; but this current slackens or ceases altogether at other times of year. The gulf also receives a surface drift from the offing of Cape Sable, into the composition of which cold banks water from the east, slope water from the Scotian eddy, and tropic water all enter in proportions that can not yet be stated.

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[49] For further discussion of this subject as it concerns the Gulf of Maine, see Bigelow, 1915, p. 255, and 1917, p. 239.

At most times there is no dominant drift into the gulf across Georges Bank, but on rare occasions overflows of tropic water take place at the surface, probably via that route.

The discharges of various rivers, added to rainfall, contribute annually to the gulf sufficient fresh water to form a layer half a fathom thick over its inner parts out to Georges Bank. The gulf also receives annually a blanket of rain water about a foot in thickness, in excess of the amount withdrawn by evaporation.

The gulf discharges water as a surface current around Nantucket Shoals to the westward; to some extent around the eastern end of Georges Bank,[50] and so out through the Eastern Channel.

It is not likely that the gulf ever receives water from the oceanic abyss, by upwelling, or directly from the Labrador current.

CIRCULATION IN THE GULF OF MAINE

Study of the circulation that dominates any part of the sea can be attacked in two different ways: (1) Directly, by observation with current meters or drift bottles, by ships' log books, and by interpreting the distribution of salinity and temperature, or (2) indirectly, by calculation of the hydrostatic forces tending to set the water in motion. The second method has greatly concerned oceanographers of late, and its value can hardly be overestimated in the study of ocean currents in the open sea; but its application to the Gulf of Maine is complicated by the disturbing factors introduced by the irregular contour of the bottom, the limiting coast line, and the strong tides, which not only produce currents of considerable velocity, but are constantly altering the slope of the surface. It is fortunate, therefore, that the following account can be based on the more direct methods of observation, supported by consideration of hydrodynamic forces as causative agents (p. 930).

TIDAL CURRENTS

No one can sail the Gulf of Maine without soon learning that its tidal currents run so strong that they must always be taken into account in coastwise navigation. Their velocities are so great, in fact, in most parts of the gulf, at the strength of ebb and flood, that for the ordinary observer they entirely obscure any dominant or nontidal drift that may be in progress.

No attempt has been made to add to the knowledge of the tides during our survey; but the following brief statement, condensed from the Coast Pilot, the tide tables and current tables of the Atlantic coast published by the United States Coast and Geodetic Survey (1923 and 1926), from the investigations of the Tidal Survey of Canada (Dawson, 1905 and 1908), and from other scattered sources, may be of interest.[51]

The flood, at its strength, runs northerly, the ebb southerly, along the whole line between Nantucket Shoals and the Northern Channel and likewise in the basin to

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[50] For discussion of the discharge from the gulf see p. 974.

[51] In 1912 the *Grampus* recorded the velocity of the current near the mid-period of flood or ebb, hoping to learn the approximation of the direction and velocity at its strength. The value of these measurements is discussed in an earlier report (Bigelow, 1914, p. 83).

the north (Mitchell, 1881; Harris, 1907, pl. 7). This is also the case along the west coast of Nova Scotia on the one side of the gulf and along Cape Cod on the other; but the flood runs westward into Massachusetts Bay, as might be expected from the trend of the coast line, drawing southward around the tip of Cape Cod into Cape Cod Bay. There is also a flood current from the westward into the latter, resulting from a division of the tidal wave as it strikes the shore line at Manomet Head just east of Plymouth.

The promontory of Cape Ann also marks a division in the tidal streams; for to the northward of it the flood, setting westward in toward the land, veers to the north, paralleling the coast as far as Cape Elizabeth; to the eastward of Casco Bay the general direction of the flood at its strength is NNE. toward and through the Grand Manan Channel, complicated, however, by the flood currents setting into the bays and rivers. At the mouth of Casco Bay, for example, the tides flood to the north. In the Bay of Fundy the flood sets generally toward the northeast (i.e., inward).

In a general way the ebb, at its strength, is the reverse of the flood, setting out of the Bay of Fundy in a generally SW. to SSW. direction and around the coast of Nova Scotia to the south and southeast. Along the coast of Maine, from the Grand Manan Channel to Penobscot Bay, the tide ebbs southwesterly; southerly off Casco Bay. In Massachusetts Bay the ebb is generally eastward; southerly along Cape Cod.

Generally speaking, the velocity of the tidal currents is least along the sector of coast bounded by Cape Cod on the south and Casco Bay on the north, where velocities lower than 1 knot have been recorded at most of the observing stations for the flood at its strength. But the tide flows much more strongly (up to 1.8 knot) around the tip of Cape Cod and at the entrance to Boston Harbor. The Bay of Fundy stands at the other extreme, with velocities rising to 2.5 to 3 knots in the Grand Manan Channel; considerably higher even than this near the head of Minas Basin and elsewhere near the head of the bay. The velocity of the tides at strength is about 1 to 1.6 knots along the southern rim of the gulf; 1.5 to 2 knots along the west coast of Nova Scotia and out to the neighboring side of the basin.

The rise and fall of the tide is greater in the Bay of Fundy than anywhere else in the world; on the other hand, the tidal amplitude is certainly small over the offshore banks, though the rise and fall has not been measured there as yet.

The following summary of the rise and fall at representative stations, taken from the tide tables of the Atlantic coast (United States Coast and Geodetic Survey, 1926), will illustrate the transition from the mouth of the gulf inward along its two sides for ordinary tides:

Locality	Rise and fall of tide, in feet	Locality	Rise and fall of tide, in feet
WESTERN SIDE		EASTERN SIDE	
Outer shores of Cape Cod	4.3- 7.1	Shelburne, Nova Scotia	6.5- 7.9
Provincetown	7.5-11.1	Yarmouth, Nova Scotia	16.3-17.7
Gloucester	7.2-10.8	BAY OF FUNDY	
Portland	7.9-11.3	St. John	23.7-25.1
Bar Harbor, Mount Desert	9.2-12.6	Digby	27.2-28.6
Cutler (at western end of Grand Manan Channel)	12.9-16.3	Head of Minas Basin	48.7-50.1

DOMINANT OR NONTIDAL DRIFT

In the preceding summary of the tidal currents, directions and velocities are given for the flood and ebb at their strength. In some localities the direction continues virtually constant throughout ebb or flood, as the case may be. In most parts of the gulf, however, the current is to a greater or less extent a veering one, and there is some difference in velocity between flood and ebb. The resultant of movement by which any particle of water would fail to return at the end of any given tidal period (averaging 12 hours and 25 minutes) to the position from which it started its journey, is the dominant drift. The name "nontidal" is commonly used for this; the other appellation just given is preferable, however, there being some evidence that the dominant drift which we have been able to demonstrate for the Gulf of Maine has its source in the tidal currents.

On the high seas, where tidal currents are weak and the dominant drifts are often stronger, the ocean currents, as we now know them, have been charted chiefly by digestion of the drifts reported in the log books of passing ships. This source of information has failed to demonstrate any dominant set (as distinguished from tidal currents) in the Gulf of Maine, as might be expected where the tides are so strong and the resultant movement, if any, comparatively so weak.

MEASUREMENTS OF CURRENTS

A considerable number of measurements of the tidal currents have been made in the Gulf of Maine by the United States Coast and Geodetic Survey at the following localities: Portland lightship off Cape Elizabeth, near Cashes Ledge, three stations between Cape Ann and Cape Cod at the mouth of Massachusetts Bay, Boston lightship off Cape Cod, many stations at the mouth of Nantucket Sound and in the region of Nantucket Shoals, Nantucket lightship, and at a series of stations situated along the southern rim of the gulf from the South Channel to the offing of Cape Sable.

The Tidal Survey of Canada, under Doctor Dawson's direction, carried out an extended survey of the tidal currents at 19 stations distributed around the Nova Scotian coast from the offing of Shelburne to the Bay of Fundy, and within the latter, in the years 1904 and 1907 (Dawson, 1905 and 1908).

One current station also was occupied off Gloucester by the *Albatross* in March, 1920 (station 20051); and measurements of the velocity and direction of flood or ebb were made by the *Grampus* in the summer of 1912 at several localities in the western side of the gulf.

Thus, the western, southern, and eastern sides of the gulf are so well covered that these measurements could hardly fail to reveal the dominant set (if there be any) for that part of its periphery; but no systematic study has yet been made of the tidal currents along the eastern coast of Maine between Portland and the entrance to the Bay of Fundy.

Before proceeding to analyze these data we may first consider briefly what sort of information they may be expected to yield.

Readings of the current meter (or the simpler method of employing a float) give the rate of the current over a known interval of time and its direction.[52] These, then, are reduced to average velocities and directions for each tidal hour after the time of high water at some neighboring station of reference, and it is in this form that they appear in the current tables published in the United States Coast Pilot (United States Coast and Geodetic Survey, 1911, p. 151) and in the current tables for the Bay of Fundy (Dawson, 1908). In all such tables the direction stated is that toward which the current flows, referred to the true meridian. In other words, a "northeast" current is just the opposite of a "northeast" wind.

To plot the course which an imaginary body, floating in the water, would travel during the period from one high tide to the next, is perhaps the most graphic way to bring out the existence or absence of a dominant drift at any given locality. If the flood and ebb currents are exactly opposite in rate, duration, and direction, such a float would return precisely to its starting point, for there would be no resultant drift. In all probability, however, this would never happen in any part of the Gulf of Maine. If, with ebb and flood opposite in direction throughout their respective duration, one were stronger than the other, a dominant set would result parallel to the direction of the stronger. This condition is to be expected in narrow channels, such as the Grand Manan Channel, and close in along some parts of the coast line; but in most parts of the gulf the direction of the tidal current changes from hour to hour, running in a comparatively constant direction for only a few hours when ebb or flood is at its strength. In some localities the tidal current is perfectly rotary, with its direction veering uniformly throughout the half-tidal day. Such a state, for example, is to be expected about 16 miles to the eastward of Nantucket Shoals light vessel (United States Coast and Geodetic Survey, 1912, p. 10).

In the Gulf of Maine and on its offshore banks tidal currents veer always to the right—i. e., with the hands of the clock—most rapidly, in most cases, at the times of high and low water. Thus, a particle of water or any floating object, such as a buoyant fish egg, drifting during a tidal period, would follow a course varying in different parts of the gulf from a closed circle (bringing it back close to its starting point), through various types of veering spirals, to courses nearly opposite in direction for the two tides but unequal in distance. In most parts of the gulf, therefore, any such floating object would not follow the dominant or nontidal set *directly*, but in a zigzag or spiral course, traveling a much greater distance in the daily tidal components than the distance made good along the azimuth of the nontidal set.

The dominant set that results from a veering current may be deduced in various ways. If calculation be preferred, an approximation is easy with the ordinary navigational traverse tables in precisely the same way the navigator calculates, from his dead reckoning, the distance and course made good for the day.

In most cases a graphic method of summation is to be preferred. The following (now in common use and recently described in detail by Mavor (1922)) is, perhaps,

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[52] It should be borne in mind that in tabular statements of currents the words "velocity" and "distance" are not synonymous; for, obviously, if the current is flowing at a rate of 1 mile per hour at one hour, and at 2 miles per hour an hour later, the distance made good during the interval is neither 1 mile nor 2 miles, but the mean of the two. This caution is added because some of the published tables of currents have been ambiguous in this respect.

the most convenient and yields approximations close enough for most purposes: Lay down a meridian, marking it N. and S. Then simply plot, to scale, the average distance and direction of the current for each successive hour, as successive lines, giving to each the correct compass bearing, commencing with high water as the starting point. Then the distance by which the location reached at one high water fails to coincide with the preceding high water, measured by the same scale, gives an approximation to the distance covered by the dominant set in one tidal day. The angle between the line connecting the two and the meridian first laid down gives the approximate direction.[53]

It is obvious that the smaller and more frequent the time intervals for which the mean velocity and direction are determined by the current meter, the closer will be the approximation yielded by this method of graphic summation, or by any other.

The work of the two governmental surveys just mentioned (of Canada and of the United States) has been directed primarily to the study of the tides as these affect navigation. Mitchell (1881), however, showed that resolution of the periodic observations at stations in the South Channel, on Georges Bank, and in the Eastern and Northern Channels demonstrated a dominant or nontidal drift at every station, in some cases of considerable velocity. A nontidal drift has also been published for many stations off Cape Cod and in the region of Nantucket Shoals (United States Coast and Geodetic Survey, 1912, chart to face p. 9), as well as for the vicinity of Cashes Ledge (Harris, 1907), long before the general importance of these drifts in the general circulation of the gulf was appreciated.

Dawson (1905, p. 16), on the other hand, believed that the currents in the eastern side of the gulf were strictly tidal, showing no "general movement of the water in any one direction in this region which is at all well marked." Mavor (1922), however, on submitting Dawson's current tables to the method of graphic summation described above, found that a dominant drift was demonstrable at every station, varying in "distance made good" for a single tidal period from about 1 mile to about 6½ miles. Dominant drifts of greater or less magnitude also result from tidal measurements taken at Portland and Boston lightships by the United States Coast and Geodetic Survey and at our *Albatross* station off Gloucester. The number of current stations is now so considerable that the presence of some such set is certainly characteristic of the parts of the gulf which they cover.

Some resultant drift in one direction or another is, in fact, to be expected anywhere in the open sea, set in motion by the temporary effects of the winds alone, if from no other cause. Whether or not such drifts as are revealed by measurements of the tidal currents can be interpreted as evidence of a dominant movement of the water as a whole depends, therefore, on their relative constancy at given stations and on whether they are consistent in direction, one with another, over considerable areas.

This last criterion can be tested most readily by plotting on a general chart of the area the dominant drifts calculated for the various stations.

The current arrows on such a chart for the Gulf of Maine (fig. 173) show this requirement met to a degree somewhat surprising when we remember that the observations were scattered through a long series of years and that the "sets" at the

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[53] It is convenient to use a position plotting sheet, such as can be had from any dealer in navigational supplies.

individual stations varied widely in their duration, some being continued through several successive months and others only for a few days. Even if nothing else whatever were known of the movements of the water in the Gulf of Maine, these arrows

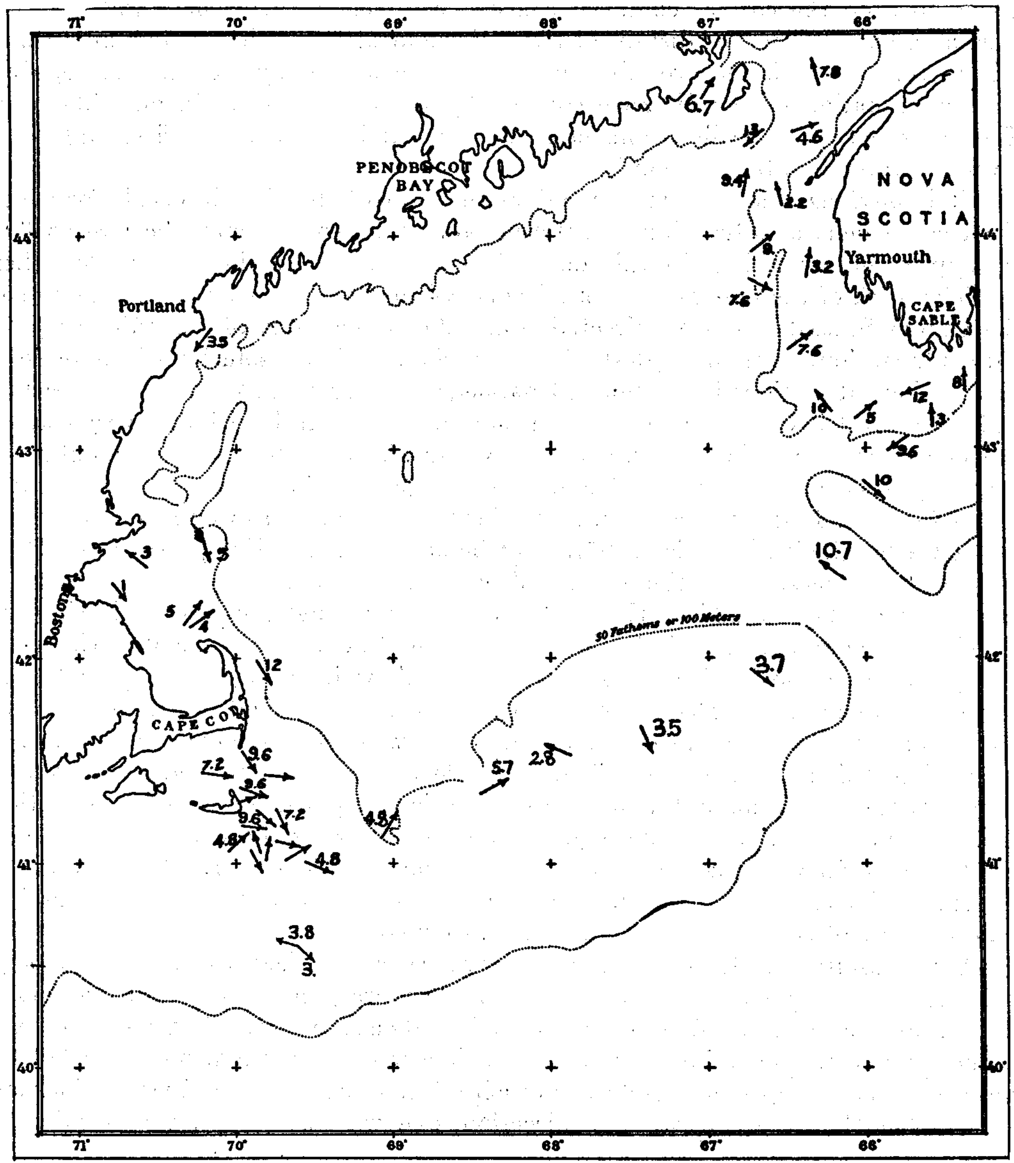

FIG. 173.—Direction and velocity, in miles, of the non-tidal current, per tidal day of 24 hours and 50 minutes, at stations of the United States Coast and Geodetic Survey and of the Tidal Survey of Canada. The feathered arrow is for the one *Albatross* station (20051)

would of themselves be strong evidence of a general tendency inward and northward along the western shores of Nova Scotia and out to the southeastward past Cape Cod and the Nantucket Shoals region for the summer and autumn months when the current measurements were taken.[54] Mavor (1922, p. 109) has already emphasized the inward movement thus indicated around Nova Scotia and so into the eastern side of the Gulf of Maine. The drift to the westward past Cape Sable is shown to be irregular, however, and perhaps intermittent, for a very rapid dominant drift toward the west of about 12 miles per day, at Dawson's station R in the offing of Cape Sable, contrasts with contrary and much weaker resultant currents at two localities nearby (Dawson's stations P and Q). In the same way the water in the offing of Shelburne was setting strongly in toward the shore on June 25 to 29, 1907, showed no dominant drift in any direction at a neighboring station two weeks later,[55] but was drifting toward the southwest at a rate of about 8 miles per day on July 27 to 28, 1914 (Bigelow, 1917, p. 203, station 10231; current measurements at 6 meters depth with Ekman current meter).

The most that can be said is that the current arrows show some movement to the westward past the cape at times during the summer.

The general tendency northward along the western shores of Nova Scotia, toward the Bay of Fundy, is decidedly impressive, because not one of the arrows, as calculated from Dawson's tables (1908), runs counter to this rule, the only exceptions being two (his stations L and M), which point almost directly in toward the land. The arrows also show the water drifting into the Bay of Fundy along its southern (Nova Scotian) side, then turning northward toward New Brunswick and out again to the eastward and southward of Grand Manan. In the channel on the northern side of the latter, however, the water has been found to set inward toward the Bay of Fundy, suggesting a clockwise circulation around Grand Manan, which corroborates the local report that the flood current predominates over the ebb along the eastern part of the coast of Maine (Coast Pilot).

It is unfortunate that no measurements of currents are available for any points between the Bay of Fundy, on the east, and Portland lightship, to the west, for the tides run strong along this sector of the coast line.

At Portland lightship the currents are weak but slightly rotary (United States Coast and Geodetic Survey, 1923, p. 69).

The Coast and Geodetic Survey has supplied the following statement of the dominant (nontidal) set for several 29-day series at this location (lat. 43° 31′ 30,″ long. 70° 05′ 38″).

Duration of series	Rate per day (24 hours) in miles	Direction	Duration of series	Rate per day (24 hours) in miles	Direction
Oct. 3-31, 1913	11.3	S. 67° W.	July 1-29, 1919	2.4	N. 62° E.
Nov. 1-29, 1913	9.6	S. 31° E.	Aug. 1-29, 1919	2.2	S. 74° W.
Nov. 30-Dec. 28, 1913	11.3	S. 11° W.	Sept. 1-29, 1919	.5	N. 47° E.
June 1-29, 1919	4.3	S. 36° W.	Oct. 1-29, 1919	1.7	N. 58° E.

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[54] So far as I have been able to learn, the only winter measurements made in the Gulf of Maine have been at Nantucket Shoals Lightship and one *Albatross* station off Gloucester (station 20051, p. 857).

[55] The resultant drifts for these two stations (Dawson, 1905 and 1908, statations S and T) are taken from Mavor's chart (1922, Pl. IV).

It is natural to think of the wind as partly responsible for these variations in the direction and velocity of the drift, and this is borne out by the following table giving the wind movements and directions at Portland, Me., for each month, and the resultants calculated therefrom by traverse tables.[56]

Month	Wind movement, miles								Resultant
	N.	NE.	E.	SE.	S.	SW.	W.	NW.	
October, 1913	2,471	449	597	813	667	574	264	1,247	N. 2° W., 2,030.
November, 1913	933	132	425	442	915	1,736	664	1,701	S. 84° W., 2,274.
December, 1913	1,848	443	235	232	208	1,422	942	2,255	N. 50° W., 3,697.
June, 1919	362	464	836	400	1,904	584	348	875	S. 3° E., 1,290.
July, 1919	382	186	551	411	2,094	826	1,013	624	S. 28° W., 2,279.
August, 1919	382	382	623	505	1,455	863	535	983	S. 33° W., 1,247.
September, 1919	690	575	485	462	2,088	638	504	1,097	S. 27° W., 1,118.
October, 1919	695	407	449	679	1,116	870	758	1,020	S. 73° W., 1,073.

When the directions and velocities of winds and currents are compared for the individual months it becomes clear that the drift is not purely a wind current, though considerably affected by the wind. With winds prevailing from anywhere between north and west, the drift has a southerly component, driven eastward and offshore by strong west winds (as in November, 1913), but setting toward the southwest, when the average wind direction is between north and west. It is when drifting southward (whether with an easterly or a westerly component) during periods when winds prevail between west and north that the surface set attains its greatest daily velocities of 9 to 11 miles per day. By common knowledge this applies also during northeast winds. During the one month (June, 1919) when south winds prevailed, the current ran, none the less, toward the southwest, though held back by the head wind to an average rate of only about 4 miles per day. The dominant drift was also very slow (0.5 to 2.4 miles per day) during the three months when southwesterly winds prevailed, setting against the wind (WSW.) for one month, but with the wind (between north and east) during the other three.

According to this correlation between current and wind, the direction of the nontidal current at this station is between WSW. and SE. and reaches a considerable velocity when westerly or northerly winds prevail; but its inherent stength is so small that southerly winds greatly reduce its velocity, or may even reverse it and produce a slow surface drift toward the northeast.

The wind table for Portland (p. 965) shows that the average direction of the wind there, from early autumn until April, is between northwest and a few degrees south of west.[57] Consequently we may assume that the dominant sets recorded at the lightship for the months of October, November, and December are representative for autumn, winter, and for the first two months of spring. These combined (by the traverse tables) give a resultant movement toward the south and west (S. 15° W.) at an average rate of about 8 miles per day. In spite of the prevalence of southwest winds in summer the resultant of the combined drifts for June, July, August,

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[56] From data supplied by the United States Weather Bureau. The directions are those from which the wind blows, as in every-day parlance.

[57] Calculated on a time-percentage basis.

and September (similarly representative of that season) is a very slow set toward the southwest at less than 1 mile per day. If all the sets for all the months be combined, the resultant drift is toward the south by west ½ west (S. 18° W.) and its average daily rate about 3½ miles per day.

The underlying dominant drift at Portland lightship is thus shown to be southerly, so far as the general transference of water is concerned, and it is so shown on the chart. Westerly winds may give it an offshore (easterly) component; and persistent southwesterly winds, such as prevail in summer, may reverse the drift, driving the surface water to the northward and eastward. Such reversals, however, are only temporary, and while operative produce drifts much slower than the dominant southerly movement. It is only while the nontidal current is setting toward the southern half of the compass that it has velocities of 4 miles per day or greater.

No measurements have been made of the currents between Portland lightship and Cape Ann, but observations taken by the United States Coast Survey at a point 10 miles southward from Cape Ann, on September 27 and 28, 1877 (U. S. Coast Pilot, 1911, p. 151), showed a dominant set of about 3 miles per day toward the WNW. (N. 66° W.) for that particular 24 hours. Fourteen miles to the southeastward of this we found a dominant set of about 5.4 miles per day toward the SSE. (S. 26° E.) at a depth of 5 meters (with the Ekman meter) on March 1 and 2, 1920 (station 20051, p. 857). These drifts, approximately at right angles to each other, probably represent the dominant tendency at their respective locations more closely than might have been expected of one-day sets, because drift-bottle experiments also indicate a tendency inshore and into Massachusetts Bay from the inner of these two stations (Coast Guard station), southerly across the mouth of the bay from the outer (p. 890).

At Boston lightship (situated near the head of Massachusetts Bay, about 9 miles off the mouth of Boston Harbor) there is a very slow dominant drift toward the eastward, a 29-day series of observations (from September 24 to October 22, 1913) giving a resultant of about 2.6 miles per 24 hours toward the S. 6° E., while a second 58-day set (October 28 to December 19, 1913) showed a dominant drift of about 1 mile per day toward the N. 24° E.[58] These two combined point to a general dominant movement of the surface stratum toward the SSE. (S. 25° E.) at the rate of slightly less than 1 mile per day, and it is so shown on the chart (fig. 173). A dominant set outward from the head of the bay toward its mouth is thus indicated in its southern side, but one governed so much by the direction of the wind that the surface water may make but a short distance good in this general direction over a considerable period.

The dominant drift at a station in the channel, between the tip of Cape Cod and Stellwagen Bank, where the tidal currents were measured by the Coast Survey on August 24 and 25, 1877 (Coast Pilot, 1911, p. 151; lat. 42° 07′, long. 70° 15′), was toward the N. 53° E. at a rate of about 4 miles per day, with about 5 miles per day (2.5 miles for 12 tidal hours) toward the N. 36° E. on the southern side of Stellwagen Bank, a few miles to the northward, on September 17, 1855 (Coast Pilot, 1911, p. 151; lat. 42° 10′, long. 70° 16′).

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[58] Information supplied by U. S. Coast and Geodetic Survey.

The directions and velocities given on the chart (fig. 173) for the stations off Cape Cod and in the region of Nantucket Shoals are copied direct from the Coast Pilot (1912, chart to face p. 9; based on observations taken by the U. S. Coast and Geodetic Survey). A south-southeasterly drift of about 12 miles a day at a station 7 miles off Nauset Light illustrates the general tendency toward a southerly movement of the water along Cape Cod, mentioned in the Coast Pilot. Observations taken at the Pollock Rip lightship and at Round Shoal lightship, at the entrance to Nantucket Sound, from June 20 to September 14, 1911, have also brought out dominant drifts toward the southeast at rates, respectively, of 9 to 10 and 2 to 3 miles per 24 hours. By this evidence, corroborated by bottle drifts (p. 886), the surface water sets southerly across and out of the eastern end of Nantucket Sound, not into the latter. This is corroborated by an east-southeasterly set of about 7 miles per 24 hours, recorded at a station 4 miles within the sound (2 miles south of Handkerchief Shoal lightship).

Sets of varying duration, taken by the Coast and Geodetic Survey at 11 stations in the general region of Nantucket Shoals, show a general dominant set between south and east, roughly paralleling the chief axis of the shoal ground, at rates varying from about 2 miles per day to about 14 miles (average about 3 miles). However, this is complicated by evidence of subsidiary eddying movements, such as might be expected over this uneven bottom, where strong tidal currents are complicated by rips and deeper channels.

Earlier studies pointed to the conclusion that the tidal currents at a point about 16 miles to the eastward of Nantucket light vessel are not only rotary but run at an equal velocity at all hours (Coast Pilot, 1912, p. 10); and it seems to have been taken generally for granted that there is no dominant set at the lightship, which is situated about 10 miles to the southward of the 40-meter contour of the shoals and 42 miles SSE. from Nantucket Island (lat. 40° 37′, long. 69° 37′), but that the currents there are purely tidal. This, however, is contradicted by 19 sets of current measurements, each of 29 days' duration, taken at this lightship by the United States Coast and Geodetic Survey in the months of June, July, August, September, October, November, December, February, March, April, and May of the years 1911, 1912, and and 1914, tabulated below.[59] In 13 cases a dominant set results toward the north and west; a set toward the south and east in four; and one series showed no appreciable set in either direction, as tabulated.

Dominant set at Nantucket lightship for various months

Month and year	Direction of dominant set	Drift per 24 hours
June, 1914	N. 46° W	2.2
June-July, 1914	N. 55° W	2.2
June-July, 1911	N. 5° E	1.1
July, 1914	N. 53° W	2.7
July, 1911	N. 25° W	1.9
August, 1914	N. 45° W	4.8
August, 1911	N. 53° W	3.8
August-September, 1911	N. 45° W	2.4
September, 1914	N. 74° W	7.4
September-October, 1913	N. 89° W	5.3
Do.	N. 80° W	8.2
October, 1913	N. 86° W	5.3
November, 1913	S. 68° E	2.4
December, 1913	S. 44° E	4.0
February, 1914	S. 51° E	2.9
March, 1914	S. 40° E	1.0
April, 1914	N. 75° W	1.4
May, 1914	N. 62° W	4.3

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[59] Data supplied by the U. S. Coast and Geodetic Survey.

Analysis of these sets shows a dominant drift toward the north and west (average direction about NW. by W.) during the spring, summer, and early autumn, averaging about 3.4 miles per day; but about as strong a southeasterly set (3 miles daily) during the late autumn, winter, and early spring, averaging about S. 50° E. in direction. If January and February be credited with about the same dominant drift as is recorded for December and March, the average set of water for the year works out at about 1.3 miles per day toward the N. 74° W. The rate has averaged lowest (less than 0.1 knot) from March through June, and drifts as strong as 0.2 knot have been recorded only during the months from August to December, a fact of some interest in connection with the discharge of surface water from the gulf (p. 974). This series of observations gives evidence of a considerable balance of movement of water toward the WNW. past the southern slopes of Nantucket Shoals, and whether the set be in that direction or toward the southeast, it is away from the gulf in either case.

This seasonal reversal in the direction of the dominant current is probably caused by the wind, with the southeasterly drift of winter reflecting the prevalence of strong northwest winds at that season; but the fact that the summer drift toward the west or northwest is not parallel with the prevailing southerly and southwesterly winds, but at right angles to them, reveals the dominant tendency for the water here to move westward.

Current measurements taken at eight stations along the southern rim of the the Gulf of Maine by the United States Coast and Geodetic Survey in 1877 show in each case a considerable nontidal resultant; and the indicated drift at any one of these may have been affected by the wind, for all were of short duration. However, they prove so consistent with the theoretic expectation of a clockwise movement around a shoal (p. 972) that they are probably representative of the prevalent summer state. The resultant drifts, as calculated by Mitchell (1881, p. 189, table 8), are as follows:

Station	Latitude		Longitude		Region	Directions	Velocity per 24 hours[1]
	°	′	°	′			*Miles*
1	41	10	68	55	South Channel	N. 31° E.	4.5
2	41	21	68	23	Northwest slope of Georges Bank	N. 79° E[2]	5.7
3	41	31	67	52	West side of Georges Shoals	N. 70° W[2]	2.8
4	41	36	67	24	East side of Georges Shoals	S. 14° E.	3.5
5	41	56	66	28	East end of Georges Bank	S. 42° E.	3.7
6	42	25	66	08	Eastern Channel	S. 76° W?	6.0
6	42	25	66	08	Do.	N. 51° W	10.7
7	42	50	65	56	South side of Northern Channel	S. 51° E.	7.3
8	43	04	65	41	North side of Northern Channel	S. 59° W.	4.7

[1] The U. S. Coast and Geodetic Survey writes that "resultant," in Mitchell's (1881, p. 189) original account, refers to the set for a tidal day of 24 hours and 50 minutes. This is reduced here to the set per 24 hours.

[2] The dominant drift is given as southeasterly at station 2, northeasterly at station 3, by Harris (1907, chart 7), and in the 1912 edition of the Coast Pilot (1912, chart to face p. 9); but a fresh calculation of the nontidal set at these stations by the Coast and Geodetic Survey shows a very good agreement with Mitchell's results.

These drifts indicate a general movement of the water northwestward around the western side of Georges Bank and southeastward over the eastern side, which is corroborated by bottle drifts (figs. 174, 176). They also suggest a subsidiary clockwise movement around the shoal part of the bank, drifting northward around its western flank and southward past the eastern flank. Drifts into the Gulf of Maine basin, at considerable velocities, result from the two stations in the center of the Eastern Channel.

At the time these observations were made the Northern Channel seems to have been dominated (as basins generally are in our latitudes) by an anticlockwise drift, southwesterly (toward the Gulf of Maine) in its northern side and southeasterly (away from the gulf) in its southern side. This latter drift, with the inward current in the Eastern Channel, suggests that Browns Bank was then the center of a clockwise eddy.

Current measurements also were taken in the center of the gulf, near Cashes Ledge (lat. 42° 53′, long. 68° 54′), on September 1 to 4, 1875, through a period of 58 hours, from which Harris (1907, pl. 7) has deduced a southerly set of about 4 miles per day. This agrees with the clockwise circulation to be expected around Cashes Ledge, this station being situated on its southeastern slope. Examination of the original data (supplied by the U. S. Coast and Geodetic Survey), however, makes it more likely that the dominant set varied with the wind there during the period of observation. The first 48 hours of the set (which apparently covered two tidal periods, because extending from "no current" to "no current") show a resultant toward the S. 26° W. of about 4 miles per 24 hours, as Harris represents it; but this period includes 8 hours (in groups of 3, 1, and 4) when no readings were taken, but during at least four of which the current almost certainly had an easterly component, judging from the stage of the tide as indicated by the veering of the current. The successive hourly directions also proved much more nearly rotary for the second tidal period than for the first, and with wide variation in its velocity while running in corresponding directions. It is wisest, therefore, to attempt no deduction of the dominant direction of the set from these data.

SUMMARY

The current measurements so far taken in the gulf when combined indicate the following circulatory movements: In the eastern side of the gulf the tendency is northward along Nova Scotia into the Bay of Fundy in its southern side, northward toward New Brunswick, and out of the bay along the south side of Grand Manan, with a counterflow into the bay via the Grand Manan Channel.

There is a gap in the observations for the coast section between Grand Manan and Cape Elizabeth. Off the latter the general set is southerly, though often deflected or temporarily reversed by the wind.

Two drifts are indicated in the region of Massachusetts Bay—one anticlockwise around its coast line and the other southerly across its mouth and down along Cape Cod. The drift is out to the eastward from Nantucket Sound, generally southerly and easterly past Nantucket Shoals. The records taken at Nantucket Lightship show a veering to the west and northwest around the shoals in summer, though not in winter. Two clockwise movements are suggested farther east—one around Georges Bank as a whole and a smaller one around its shoalest part.

In general, the dominant set has been found most rapid in the region of Cape Cod and Nantucket Shoals, averaging about 8 miles daily. The average velocity (about 7 miles per 24 hours) is nearly as great for the stations along the west coast of Nova Scotia and in the Bay of Fundy; but the resultant set into this side of the gulf is not so rapid, because most of the stations show components either to the west or to the east. Perhaps 5 miles per day approximates the rate at which a bottle might be expected to drift northward along Nova Scotia by this evidence.

EXPERIMENTS WITH DRIFT BOTTLES

Measurements with the current meter, such as have just been discussed, give both the direction and the rate of the dominant set, as well as of the tidal currents, at that particular place and time, assuming always that the observations are taken at frequent enough intervals and extended over a sufficient period of time.

The setting free and recovery of a drift bottle can never yield information so definite, because only the two end points of its journey are known, the route it has traveled from the one to the other always remaining a matter for deduction. Our drift bottles, furthermore, reflect the dominant movement of the uppermost stratum of water only; a fathom or two deep, at most, for the bottles with the longest drags. Neither does the drift of a bottle necessarily reproduce the drift that would have been followed by a particle of water, because the bottle floats on the surface, while the water may sink to lower levels by vertical currents, while new water may well up to the surface from below to take its place.

Because only the end points of the drifts are known and the intervening tracks can only be assumed, their value depends on a number of factors, especially on their consistency, one with another; the length of time they are adrift; the extent of the oceanic area covered; and on general information from other sources as to the local currents. In all these respects the Gulf of Maine has proved an especially favorable region for the study of the dominant circulation by the drift-bottle method. Since all the drifts from all the lines set out have, without exception, proved reducible to one scheme, entirely consistent with the current measurements (p. 866) and with general report as to the dominant set along various parts of the coast, with temperature and salinity, with the distribution of the plankton, and with the internal hydrostatic forces (p. 936), I believe they may be taken as representing the main features usually prevailing in spring, late summer, and early autumn.

The greater the time interval between release and recovery, the greater does the uncertainty become, because the longer the bottle is afloat, the greater distance it may have covered in its journey—i. e., the farther its track is apt to have diverged from the direct point to point line. By this same reasoning, when bottles are released in numbers the time interval becomes an important factor in deducing their probable tracks. If, for example, bottles released near Cape Elizabeth were to drift repeatedly to a point in Nova Scotia in as short a period as bottles released at Mount Desert, it is a fair assumption that the latter have diverged enough from the direct route to make their journey approximately as long as that of the former, assuming, of course, an approximately equal rate of drift for both. I should also point out that in a region where the tidal currents are as strong as they are in the Gulf of Maine, little information as to the *dominant* drift is to be had from a bottle until it has been adrift through several tidal periods. Consequently, when a bottle set adrift within 3 or 4 miles of shore at the beginning of the flood tide is recovered on the beach it does not mean that a dominant inshore set brought it in, but simply that it drifted and stranded with the tide.

These remarks are elementary, but are introduced here because, in conversation, I have found a very general tendency to ascribe a direct drift to any drift bottle.

BOTTLES SET OUT IN THE BAY OF FUNDY

The first systematic attempt to plot the dominant or nontidal circulation of any part of the gulf by the use of drift bottles was undertaken by the Atlantic (St. Andrews) biological station of the Biological Board of Canada in the summer of 1919, when 396 bottles were set adrift on lines crossing the Bay of Fundy, with results so positive that they are extremely welcome for the light they throw on the returns from the several series subsequently released in the open gulf by the Bureau of Fisheries. The complete data of localities of release and recovery are given by Mavor (1922), who has also discussed the probable tracks in such detail that a brief summary will suffice here.

The recoveries[61] may be divided into two groups—first, from within the Bay of Fundy, and second, from the Gulf of Maine.[62]

Bottles picked up within the Bay of Fundy were all set out in August and September, 1919, along lines at right angles to the general axis of the bay. Five bottles, set out at distances of 1 to 10 miles from shore on a line running northwest from Brier Island, at the mouth of the bay, and picked up along its Nova Scotian shore after drifts of 25 to 65 miles, show a definite set inward along the southern side of the bay consistent with the current measurements that have been taken there (Mavor, 1922, p. 116, fig. 13). One of these traveled at a rate of more than 4 nautical miles per day. It seems, however, that this inward drift involved only a narrow belt, probably not more than 6 or 7 miles wide at the time, because only one bottle from the next line to the west (one set adrift about 7 miles from the shore of Digby Neck) took this route, while two others released closer in to the land drifted across the bay to the New Brunswick shore and to Grand Manan.

Most of the recoveries from all the other lines were from points on the New Brunswick shore; a few were from the neighborhood of Grand Manan and a few (to be considered later) were in the Gulf of Maine outside the bay. Mavor's (1922) analysis brings out the interesting fact that the bottles that were picked up farthest east on the New Brunswick shore[63] were all set out in the southern side of the bay within 12 miles of the Nova Scotian shore.

The bottles set out in the southern side of the bay (several lines) thus exhibit one or the other of two rather definite tendencies. Those set adrift near the Nova

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[61] Only those reported within 4 months after the bottles were set out are considered here.

[62] Mavor (1922, p. 116) states that "all the drift bottles which have been recorded from outside the Bay of Fundy were picked up in the Gulf of Maine." Two also have been reported from Europe (Mavor, 1921; Moor [Mavor], 1921).

[63] Between Musquash Harbor (long. 66°15′W.) and St. John.

Scotian shore at the mouth of the bay, or inward to Digby Gut, tended to drift eastward, hugging the southern coast. Those set afloat more than 5 to 10 miles out from land in the southern side of the bay rarely stranded on that shore, but usually drifted northward across the bay to the New Brunswick shore. It is evident that they did not go far up the bay, for only one bottle was picked up east of St. John, while most of the recoveries of bottles set out on the Nova Scotian end of the innermost line were west of the longitude at which they were set out.

Bottles set out in the northern side of the Bay of Fundy showed a westerly drift, the majority of recoveries coming from the New Brunswick shore west of Point Lepreau (especially concentrated in the region of Passamaquoddy Bay), with some from the southern and eastern sides of Grand Manan.

The southern edge of the inflowing current in the southern side of the bay hugged the shore—witness the stranding of bottles along Nova Scotia. Its outer (offshore) edge, on the contrary, showed as evident a tendency to veer, anticlockwise, across the bay toward the New Brunswick shore, and so to eddy westward, made evident by the tendency of bottles from the Nova Scotia side to strand farthest east (inward), along New Brunswick, and for bottles set out in the northern side of the bay to follow the coast line of New Brunswick farther to the westward.

Some idea of the routes followed by bottles crossing from the Nova Scotian to the New Brunswick side of the bay can be gained from the relative lengths of the intervals between release and recovery,[64] when these prove as consistent as they did in this instance. Mavor (1922, p. 116) has already commented on the fact that the bottles set out on the Nova Scotian end of a line abreast of Point Lepreau (his line G) averaged longer afloat than those set out on the New Brunswick end, suggesting that they took a longer route, going up on the Nova Scotian side and down on the New Brunswick side. The time intervals between release and recovery for bottles drifting from Nova Scotia to New Brunswick were also longer for those set out nearest the mouth of the bay (25 to 48 days) than for those set adrift farther in the bay (8 to 22 days), with a discrepancy much wider than the varying width of the bay would account for. Bottles set out on the southern end of the innermost line and picked up eight days later on the New Brunswick side must have followed a comparatively direct route in their crossing. A longer time interval for bottles set out nearer the mouth of the bay points to a more extended circling drift; but the fact that on the whole bottles set out farther and farther east along the Nova Scotian side fetched up farther and farther up the bay in the New Brunswick side is evidence that the south-north drift was of considerable breadth.

A cross section of the Bay of Fundy from Nova Scotia to Grand Manan would thus have shown a rather sudden transition, at the time, from a current flowing toward the southwest in the northern side to a northeast drift in along the southern shore. The fates of four bottles that were set out close together on a line abreast of Point Lepreau, but were picked up far apart and on opposite sides of the bay 37 to 70 days later, locates the boundary of these two currents nearer Nova Scotia than New Brunswick (Mavor, 1922, p. 116).

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[64] Always remembering that a bottle may lie a long time on some seldom-visited beach.

These bottle drifts justify Mavor's (1922) general conclusion that in the summer of 1919 the water was drifting in along the southern side of the bay, circling northward across to the New Brunswick shore about abreast of St. John, setting west and southwest along New Brunswick and out of the bay past the southern side of Grand Manan. This, as he points out (1922, p. 116), is entirely consistent with the dominant set resulting from Dawson's current measurements; more consistant, indeed, than one might have expected of observations of these two sorts taken several years apart in such tide-swept waters.

The drift westward along New Brunswick, according to Mavor's analysis, was at a rate of at least 5 nautical miles per day. This, with the rates for the bottles that drifted inward along the Nova Scotian shore (p. 868), suggests a general daily rate of 4 to 5 miles for the periphery of the Bay of Fundy eddy.

Fifteen of the bottles set out in the Bay of Fundy in 1919 were picked up outside the bay in the Gulf of Maine—2 from the June series and 13 from the August series. The two June bottles, however, represent a much larger percentage than do the August recoveries; for only 10 bottles were set out in June, and these were the only ones picked up, whereas 220 were set out in August, most of the recoveries coming from within the Bay of Fundy. None of the September bottles (75 in number) were picked up in the Gulf of Maine.

The two June bottles were put out, respectively, 14 and 18 miles south of Grand Manan on the 18th. One was picked up at Bailey's Mistake (a cove on the north shore of the Grand Manan Channel) about midway of its length; the other was recovered in Penobscot Bay. Both of these bottles undoubtedly passed out of the bay in the outflowing current along the south side of Grand Manan; but the one circled Grand Manan, to be caught up in the indraft demonstrated by current measurements for the Grand Manan Channel; while the other, put out only 4 miles farther south, escaped this eddy and traveled westward along the coast of Maine. There is every reason to suppose that the 13 August bottles also went out of the Bay of Fundy along the south side of Grand Manan, for they show very uniform drifts. One was returned from Jonesport, Me., one from Schoodic Head, near Mount Desert, and all the rest from the Massachusetts Bay region and Cape Cod. Bottles from the innermost as well as from the outermost lines in the Bay of Fundy (Mavor's lines D and G) partook of this drift (curiously enough, however, none from the intermediate line).

Mavor (1922, p. 118) has emphasized the uniform time intervals of 7 of the 11 bottles that were picked up in Massachusetts Bay 73 to 80 days after being put out. This, with the fact that so large a proportion of all the bottles picked up outside the Bay of Fundy within four months after being set adrift were found along so short a stretch of the coast line, is evidence enough of a very definite surface drift from the northeastern to the southwestern side of the gulf during the late summer and early autumn of 1919; and the recovery of two bottles on the eastern coast of Maine makes it probable that this line of drift lay rather close in to the shore as far as the mouth of Penobscot Bay. However, since none were found between Penobscot Bay and Cape Ann they seem to have followed tracks farther out from the land along this sector of the coast line.

The distance from the Bay of Fundy to Cape Cod being about 220 miles, these bottles, as Mavor points out, must have drifted at an average rate of at least 4 miles per day. Actually, the rate was no doubt somewhat more rapid than this, because the track probably followed is approximately 260 miles, at the smallest reckoning.

The regional distribution of the recoveries in the Massachusetts Bay region is also interesting, none being from the shore line between Cape Ann and Plymouth, but seven scattered around the shores of Cape Cod Bay from Plymouth to the tip of the cape.[65] The hook of Cape Cod seems, therefore, to have acted as a sort of catch-basin for flotsam at the time these bottles were adrift, evidence that the set of surface water was then from north to south across the mouth of Massachusetts Bay, as it was in March, 1920 (current measurements at station 20051; p. 863), not around the shore line of the bay, as current measurements show it at times (p. 863).

Two bottles, evidently having crossed the mouth of the bay somewhat farther out, stranded on the outer shore of Cape Cod (near Pamet River Coast Guard Station and near South Wellfleet wireless towers), and one went to Monomoy Island at the southern angle of Cape Cod.

BOTTLES SET OUT IN THE GULF OF MAINE

The drifts of the bottles set out in the Bay of Fundy by the Biological Board of Canada in 1919 were so significant and agreed so well with the dominant set calculated from current measurements that the United States Bureau of Fisheries has since released 1,606 drift bottles in the Gulf of Maine and its tributary waters along the following lines, the returns from which are tabulated below:

DRIFT-BOTTLE RECORD, INCLUDING RECOVERIES UP TO SEPTEMBER 1, 1926

SERIES A: Bottles Nos. 1 to 300; two every half mile on a line running 125°, true, from Cape Elizabeth to the vicinity of Cashes Ledge, June 30 to July 1, 1922.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
23	43	30	06	70	04	42	Small Point Harbor, east of Littlewood Island, Me	July 26	26
26	43	29	48	70	04	06	Between Richmond Island and Cape Elizabeth, Me	July 5	5
27	43	29	30	70	03	30	Near Bald Head, Small Point, Me	July 28	28
28	43	29	30	70	03	30	1 mile east of Cape Elizabeth Lighthouse	July 4	4
30	43	29	12	70	02	54	Northwest side of Monhegan Island	Aug. 16	47
32	43	28	54	70	02	18	Richmond Island Bay, Me	July 13	13
43	43	27	06	69	58	42	Woodwards Cove, Grand Manan Island	Oct. 12	104
52	43	25	57	69	56	18	Metinic Shoal (northwest of it)	Sept. 13	75
65	43	23	48	69	52	06	Loon Point, Jonesport, Me	Sept. 18	80
70	43	23	12	69	50	40	Chebeague Island, Me	July 25	25
72	43	22	54	69	50	18	Prouts Neck Beach. Scarboro, Me	do	25
75	43	22	18	69	49	06	Boothbay Harbor, Me	Aug. 1	32
76	43	22	18	69	49	06	5 miles east of Prouts Neck, Me., opposite Richmond Island	Sept. 10	72
79	43	21	42	69	47	54	Thompsons Point, Cundys Harbor, Me	do	72
83	43	21	06	69	46	42	Birch Point, Winnegance Bay, Me	Aug. 20	51
87	43	20	30	69	45	30	South Beach, Matinicus Island, Me	Oct. 12	103
88	43	20	30	69	45	30	Eastern Wolves Island, Bay of Fundy	do	103
90	43	20	12	69	44	54	Bald Head, Casco Bay, Me	July 25	25
98	43	00	19	69	42	30	¾ mile northeast from outer John's Island, near Swans Island, Me	Sept. 1	63
99	43	18	42	69	41	54	Bay of Fundy, Nova Scotia	Sept. 18	80
105	43	17	48	69	40	02	1 mile west of Hartsville Breakwater, south shore of Bay of Fundy	Oct. 6	98
124	43	15	06	69	34	42	South side of Cedar Island, Isles of Shoals, N. H	Oct. 8	100

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[65] White Horse Beach, Plymouth; Sagamore Highlands; Sagamore Beach; Scorton Beach; North Truro; and three between Wood End and Peaked Hill Bar Coast Guard Station.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
127	43	14	30	69	33	30	2 miles off Hillsburn, Hants County, Nova Scotia	Sept. 28	90
128	43	14	30	69	33	30	New Meadows River, Casco Bay, Me	Sept. 15	77
153	43	10	36	69	25	42	1 mile north of Beaver River, county line [N. S. ?]	Oct. 26	118
165	43	08	48	69	22	06	Scotts Bay Beach, Nova Scotia	Oct. 21	113
190	43	05	12	69	14	54	Entrance of Grand Passage, Nova Scotia	Oct. 24	116
206	43	02	48	69	10	06	Digby Neck, Sandy Cove, Nova Scotia, Bay of Fundy side	Sept. 28	90
210	43	02	12	69	08	54	½ mile off west side of Isle au Haut, Me	Sept. 23	85
215	43	01	18	69	07	06	1½ miles east of Port Lorne Lighthouse, Nova Scotia	Nov. 23	146
222	43	00	24	69	05	18	Port Lorne, Nova Scotia	Oct. 21	113
230	42	59	12	69	02	54	Meteghan Cove, Nova Scotia	Nov. 14	135
241	42	57	24	68	59	18	Port Lorne, Bay of Fundy, Nova Scotia	Sept. 26	88
242	42	57	24	68	59	18	14 miles west-southwest from Digby, in Bay of Fundy, 3 miles offshore	Sept. 8	70
248	42	56	30	68	57	30	Broad Cove Breakwater, 2 miles from Point Prim Light, Bay of Fundy	Sept. 13	75
255	42	55	18	68	55	06	9 miles from Point Prim, Bay of Fundy	Sept. 28	90
264	42	54	06	68	52	42	Bay of Fundy shore of Long Island, at Central Grove, Nova Scotia	Sept. 19	81
280	42	51	42	68	47	54	Northwest from Salvages fog alarm, Nova Scotia	Sept. 5	67
284	42	51	06	68	46	42	Southern Point, Matinicus Island, Me	Oct. 11	103
299	42	48	42	68	41	54	Advocate Harbor Beach, Cumberland County, Nova Scotia	Oct. 15	107

SERIES B: Bottles Nos. 301 to 900; two every half mile, running 141° from the offing of Chatham, Cape Cod, 150 miles, July 4, 1922.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
301	41	41	00	69	53	00	1½ miles north of Coast Guard station 41, Nausett Beach, Mass	July 11	5
302	41	41	00	69	53	00	Stonewall Beach, Chilmark, Mass. (east of Old Bull bell buoy)	Aug. 26	51
303	41	40	36	69	52	36	Sakonnet River, R. I	July 30	24
304	41	40	36	69	52	36	Chatham, Mass	July 9	3
308	41	39	45	69	51	48	Cuttyhunk, Mass	Sept. 10	66
309	41	39	24	69	51	24	West side of Nantucket Harbor, mouth of jetty	Dec. 31	180
311	41	39	00	69	51	00	60 miles south-southeast of Cape Cod Light	July 21	15
314	41	38	36	69	50	36	West end, Cuttyhunk Island	Aug. 7	32
317	41	37	48	69	49	48	On Beach near north lighthouse, Block Island	Aug. 11	36
331	41	35	00	69	47	00	¼ mile north of Gay Head, Mass	Aug. 6	30
333	41	34	36	69	46	36	On Beach near southeast light, Block Island	July 7	1
334	41	34	36	69	46	36	Newport Beach, Newport, R. I	Sept. 12	67
337	41	33	38	69	45	48	South side, Marthas Vineyard Island	July 23	16
343	41	32	36	69	44	36	Chilmark, south shore Marthas Vineyard	Aug. 29	53
348	41	31	48	69	43	48	5 miles north of Finis-terre Light, France	[1] Sept. 16	------
357	41	29	48	69	41	48	75 miles southeast from Cape Cod [light ?]	Oct. 3	88
358	41	29	48	69	41	48	Hampton, Annapolis County, Nova Scotia	Oct. 21	106
362	41	29	00	69	41	00	75 miles southeast ½ south from Cape Cod Light	July 12	5
376	41	26	12	69	38	12	Between Horseneck Beach and Barney's Joy Point	Sept. 10	65
389	41	23	24	69	35	24	Head of Miacomet Pond, Nantucket, Mass	Aug. 19	43
396	41	22	12	69	34	12	75 miles south-southeast from Cape Cod [light]	July 15	8
405	41	20	12	69	32	12	48 miles south-southeast from Cape Cod Light	do	8
422	41	17	00	69	29	00	12 miles south of Sakonnet Point light	Sept. 5	60
433	41	14	36	69	26	36	Hampton, 26 miles east of Digby, Nova Scotia	Sept. 27	82
435	41	14	12	69	26	12	Lat. 42° 07′ N., long. 66° 41′ W	Oct. 11	96
445	41	12	12	69	24	12	1½ miles west of U. S. Coast Guard Station 47, Muskeget	Aug. 10	34
447	41	11	48	69	23	48	300 yards east of boat house, Fishers Island, N. Y	Aug. 16	40
462	41	09	00	69	21	00	Near Port George, Nova Scotia	Oct. 20	105
484	41	04	36	69	16	36	South shore of Marthas Vineyard, east of No Mans Land	Sept. 12	67
510	40	59	24	69	11	24	72 miles southeast by east from Cape Cod Light	July 10	3
528	40	55	48	69	07	48	West shore, Mishaum Point, Mass	Aug. 13	37
536	40	54	12	69	06	12	East-southeast ½ mile from mouth of Vineyard Sound, Mass	July 30	23
541	40	53	00	69	05	00	South Beach, Katama Bay, Edgartown, Mass	Aug. 28	52
543	40	52	36	69	04	36	Georges Bank, lat. 41° 15′	Aug. 11	35
547	40	51	48	69	03	48	On beach, Nantucket, Mass	Aug. 20	44
548	40	51	48	69	03	48	4 miles southwest of Vineyard Sound Lightship, Mass	July 29	22
557	40	49	48	69	01	48	Katama Bay, Edgartown, Mass	Aug. 13	37
569	40	47	24	68	58	24	Near Buoy, Gay Head, Mass	July 29	22
580	40	45	24	68	56	24	1 mile east of U. S. Coast Guard Station 47, Mass	July 25	18
582	40	45	00	68	56	00	Southeast shore, Block Island, R. I	Sept. 12	67
584	40	44	36	68	55	36	Horseneck Beach, Mass	July 31	24
585	40	44	12	68	55	12	On Massachusetts and Rhode Island line	July 28	21
587	40	43	48	68	54	48	Off Grace Point, Block Island	Sept. 13	68
588	40	43	48	68	54	48	Penikese Island, Mass	Aug. 2	26

[1] 1923.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
590	40	43	24	68	54	24	Crescent Beach, Block Island, R. I	Aug. 13	37
591	40	43	00	68	54	00	Middle Ground Shoal, Vineyard Haven, Mass	Aug. 9	33
593	40	42	36	68	53	36	Bathing Beach, Southampton, Long Island	Sept. 12	67
596	40	42	12	68	53	12	¼ mile north of Sakonnet Lighthouse, Sakonnet River, R. I	July 30	23
597	40	41	48	68	52	48	On Beach at Horseneck, Westport, Mass	Aug. 7	31
600	40	41	24	68	52	24	Tarpaulin Cove, Naushon Island, Mass	Aug. 26	50
602	40	41	00	68	52	00	Near Lighthouse, south beach, Gay Head, Mass	July 29	22
603	40	40	36	68	51	36	2½ miles northwest of Vineyard Sound Lightship, Mass	Aug. 1	25
604	40	40	36	68	51	36	Old Harbor Point, Block Island, R. I	Aug. 10	34
605	40	40	12	68	51	12	West Horseneck Beach, Westport, Mass	July 29	22
606	40	40	12	68	51	12	West shore Block Island, R. I	Aug. 19	43
608	40	39	48	68	50	48	Narragansett Pier, R. I	Aug. 7	31
609	40	39	24	68	50	24	North-northwest of Old Harbor Breakwater, east side, R. I	Aug. 4	28
611	40	39	00	68	50	00	1 mile north of Wasque Hill, Chappaquiddic Island, Mass	July 27	20
613	40	38	36	68	49	36	1 mile east of Coast Guard station 72, Long Island, N Y	Aug. 7	31
614	40	38	36	68	49	36	1½ miles West of Barney's Joy Point, Mass	July 29	22
615	40	38	12	68	49	12	5 miles below Edgartown, south shore Martha's Vineyard, Mass	Aug. 20	44
617	40	37	48	68	48	48	Pleasant View Beach, R. I	July 28	21
618	40	37	48	68	48	48	Westport Point, Mass	[1]Dec. 29	(2)
620	40	37	24	68	48	24	Horseneck, Beach, Mass	July 31	23
621	40	37	00	68	48	00	Horseneck Beach, Westport, Mass	do	22
622	40	37	00	68	48	00	Matunuck Beach, R. I	Aug. 8	32
624	40	36	36	68	47	36	Near Warren Point, Little Compton, R. I	July 29	22
627	40	35	48	68	46	48	Cornwall, England	[3]Aug. 14	(4)
628	40	35	48	68	46	48	3½ miles west of Montauk Light Station	Sept. 10	65
629	40	35	24	68	46	24	West Horseneck Beach, Mass	Aug. 1	25
630	40	35	24	68	46	24	South shore, Chilmark, Mass	Aug. 2	26
631	40	35	00	68	46	00	4 miles below Edgartown, south shore Marthas Vineyard, Mass	Aug. 6	30
634	40	34	36	68	45	36	2 miles northwest of Vineyard Sound Lightship, Mass	Aug. 1	31
635	40	34	12	68	45	12	1 mile southeast of Westport Harbor, Horseneck Beach, Mass	Aug. 7	31
637	40	33	48	68	44	48	3 miles south-southeast of Cuttyhunk Lighthouse, Cuttyhunk, Mass	July 28	21
638	40	33	48	68	44	48	Between North Light and New Harbor Channel, West Beach, R. I	Aug. 6	30
639	40	33	24	68	44	24	Halfway between Coast Guard Stations 66 and 67, Montauk, L. I	Sept. 16	71
641	40	33	00	68	44	00	On beach near Falmouth, Mass	Aug. 20	44
644	40	32	36	68	43	36	West end of Nashawena Island, Mass	July 29	22
645	40	32	12	68	43	12	½ mile southeast of light on beach, Block Island, R. I	July 7	1
646	40	32	12	68	43	12	Charlestown Beach, R. I	Aug. 5	29
647	40	31	48	68	42	48	10 miles west of Montauk Point, south side Long Island, N. Y	Aug. 7	31
648	40	31	48	68	42	48	Between Point Judith and Charleston, opposite East Island	Aug. 17	31
649	40	31	24	68	42	24	Sakonnet Point, R. I	Aug. 4	28
650	40	31	24	68	42	24	6 miles southeast from Sakonnet Point Light, R. I	Aug. 3	27
651	40	31	00	68	42	00	Little Compton, R. I	July 28	21
652	40	31	00	68	42	00	Easthampton, L. I	Sept. 12	67
653	40	30	36	68	41	36	Near Life Guard Station 65, Ditch Plains, Montauk, L. I	Sept. 9	64
654	40	30	36	68	41	36	½ mile east of Coast Guard Station 73, opposite Hampton Bays, N. Y	Sept. 11	66
655	40	30	12	68	41	12	East side of Block Island, R. I	Sept. 9	64
656	40	30	12	68	41	12	Sagaponack, L. I. northeast of Bridgehampton	Sept. 12	67
658	40	29	48	68	40	48	Gay Head, Mass	Sept. 3	58
661	40	29	00	68	40	00	1½ miles west of Charlestown, R. I. (?)	Sept. 17	72
662	40	29	00	68	40	00	1½ miles from light, south shore, Gay Head, Mass	Aug. 5	29
664	40	28	36	68	39	36	1 mile south of No Mans Land, Mass	July 28	21
665	40	28	12	68	39	12	Start Point, bearing north-northwest, 15 miles, England	[5]Sept. 19	(6)
666	40	28	12	68	39	12	West Beach, Horseneck, South Westport, Mass	Aug. 7	31
668	40	27	48	68	38	48	3½ miles from light, south shore, Gay Head, Mass	Aug. 5	29
669	40	27	24	68	38	24	2 miles north of Coast Guard Station 172, Kitty Hawk, N. C	Sept. 26	81
676	40	26	12	68	37	12	Coast Guard Station 176, near Manteo, N. C	Sept. 30	85
679	40	25	24	68	36	24	1 mile north of Coast Guard Station 165	Oct. 1	86
680	40	25	24	68	36	24	¼ mile north of Coast Guard Station 171	Sept. 22	77
684	40	24	36	68	35	36	1 mile north of Coast Guard Station 170	do	77
686	40	24	12	68	35	12	Near Coast Guard Station 179	Sept. 27	82
688	40	23	48	68	34	48	1 mile north of Coast Guard Station 176	Sept. 30	85
695	40	22	12	68	33	12	Kitty Hawk, N. C	Sept. 27	82
700	40	21	24	68	32	24	1½ miles west of Coast Guard Station 56, Green Hill, R. I	Sept. 12	67
702	40	21	00	68	32	00	8 miles west of Montauk Lighthouse, Long Island, N. Y	Sept. 19	74
703	40	20	36	68	31	36	1½ mile south of Coast Guard Station 170	Sept. 21	76
707	40	19	48	68	30	48	Near life-saving station, east beach, Montauk, L. I	Sept. 12	67
718	40	17	48	68	28	48	2½ miles east of Quonochontaug life-saving Station, R.I	Sept. 13	68
724	40	16	36	68	27	36	Edgartown Harbor, Edgartown, Mass	Oct. 15	100
727	40	15	48	68	25	48	1½ mile south of Coast Guard Station 9	[7]Mar. 4	(8)
728	40	15	48	68	25	48	2¼ miles north of Coast Guard Station 170, on beach	Sept. 22	77
731	40	15	00	68	25	00	The Azores	(9)	(10)
732	40	15	00	68	25	00	Off Gooseberry Neck, near Westport Harbor, Mass	Sept.	58

[1] 1923.

[2] One year 4 months and 22 days.

[3] 1926.

[4] Four years 1 month and 7 days.

[5] 1924.

[6] Two years 2 months and 12 days.

[7] 1923.

[8] Seven months 25 days.

[9] July, 1923.

[10] About 1 year.

No.	Set out						Where found	Date, 1922	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
739	40	13	24	68	23	24	2 miles south of Coast Guard Station 170, Duck, N. C	Sept. 29	84
745	40	12	12	68	22	12	West end of Baileys Beach, Newport, R. I	Sept. 13	68
749	40	11	24	68	21	24	Grand Canary Island	[1]Apr. 1	([2])
752	40	11	00	68	21	00	Southeast by south ½ south, 35 miles from No Mans Land	Sept. 20	75
753	40	10	36	68	20	36	6 miles southwest of Gay Head, Mass	Sept. 6	61
762	40	09	00	68	19	00	Point O Wood, Fire Island, Long Island, N. Y	Oct. 8	93
770	40	07	24	68	17	24	Lat. 41° 20′ 45″, long. 70° 38′ 30″	Sept. 4	59
775	40	06	12	68	16	12	2 miles east of Coast Guard Station 70	Sept. 20	75
777	40	05	48	68	15	48	½ mile south of Coast Guard Station 169	Oct. 14	99
779	40	05	24	68	15	24	1 mile south of Coast Guard Station 181	Sept. 27	112
787	40	03	48	68	13	48	Roughley, Sligo Bay, Ireland	[3]July 18	([4])
790	40	03	24	68	13	24	South shore of Marthas Vineyard, Mass	Sept. 4	59
802	40	01	00	68	11	00	South Beach, Edgartown, Mass	Aug. 29	53
804	40	00	36	68	10	36	Southwesterly shore of Marthas Vineyard, Mass	Sept. 7	62
806	40	00	12	68	10	12	¾ mile on the shore northeast from the breakwater, Sakonnet Point, R. I	Sept. 6	61
822	39	57	00	68	07	00	1 mile south of Coast Guard Station 173	Sept. 28	83
824	39	56	36	68	06	36	Horseneck Beach, Westport, Mass	Sept. 16	71
835	39	54	12	68	04	12	1 mile below Bodies Island Lighthouse, N. C	Oct. 2	87
837	39	53	48	68	03	48	½ mile north of Coast Guard Station 177	do	87
839	39	53	24	68	03	24	In Bay at Nantucket, Mass	Nov. 22	141
844	39	52	36	68	02	36	10 miles southwest by west of Sankaty light, Nantucket, Mass	Aug. 28	52
845	39	52	12	68	02	12	9 miles north of Bodies Island light Station	Sept. 18	73
890	39	43	24	67	53	24	South side of Marthas Vineyard, Mass	Oct. 1	86
900	39	41	24	67	51	24	South Beach, Marthas Vineyard, Edgartown, Mass	Aug. 28	52

[1] 1924.

[2] One year 8 months and 24 days.

[3] 1923.

[4] One year 11 days.

SERIES D: Bottles Nos. 1501 to 1600; two bottles every half mile on a line running 150° from Bakers Island, off Mount Desert, for 25 miles, August 6, 1923.

No.	Set out						Where found	Date, 1923	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
1503	44	13	19	68	10	25	Duck Island, Me	Aug. 8	2
1504	44	13	19	68	10	25	Near Baccaro lighthouse, Shelburne County, Nova Scotia	Oct. 18	73
1506	44	12	53	68	10	05	Comeau Cove, Digby County, Nova Scotia	Oct. 7	62
1510	44	12	01	68	9	25	Great Duck Island, Me	Aug. 8	2
1511	44	11	35	68	9	05	Winter Harbor, Me	[1]July 19	------
1515	44	10	43	68	8	25	Point of outer Long Island, Me	Aug. 8	2
1521	44	9	25	68	7	25	Kennebunk Beach, Me	Sept. 7	32
1523	44	8	59	68	7	05	8 miles southeast of Isle au Haut, Me	Aug. 7?	(?)
1530	44	7	41	68	6	00	Salmon River, Digby County, Nova Scotia	Dec. 17	133
1531	44	7	15	68	5	45	East side Petite Passage, Digby County, Nova Scotia	Oct. 16	71
1541	44	5	05	68	4	05	West side Egg Rock light, Hancock County, Me	Sept. 11	36
1546	44	4	13	68	3	25	Deep Cove, Isle au Haut, Me	Sept. 14	39
1547	44	3	47	68	3	05	Salmon River Beach, Digby County, Nova Scotia	Oct. 9	64
1550	44	3	21	68	2	45	Scudish Island, Me	Sept. 10	35
1551	44	3	00	68	2	45	Pubnico Harbor, Nova Scotia	[1]Jan. 4	151
1553	44	2	29	68	2	05	1¾ miles WNW. of Matinicus, Me	Sept. 12	37
1554	44	2	29	68	2	05	Clark Island, Me	Sept. 9	34
1557	44	1	37	68	1	25	Pubnico Point, Nova Scotia	[1]Jan. 4	151
1563	44	0	19	68	0	25	Pleasant Cove, Digby County, Nova Scotia	Oct. 8	63
1565	43	59	53	68	0	05	States Point, St. George, Me	Sept. 9	34
1566	43	59	53	68	0	05	Wooden Ball Island, Me	Sept. 11	36
1568	43	59	27	67	59	45	Meteghan River, St. Marys Bay, Digby County, Nova Scotia	Oct. 7	62
1576	43	57	43	67	58	25	3 miles west from Petit Manan light, Me	Sept. 13	38
1581	43	56	25	67	57	25	West side of Grindstone Neck, Winter Harbor, Me	Sept. 8	33
1584	43	55	59	67	57	05	Haycocks Harbor, Washington County, Me	Nov. 7	93
1587	43	55	07	67	56	25	Near Port George, Annapolis County, Nova Scotia	Nov. 2	88
1599	43	52	31	67	54	25	Near bell buoy, Burnt Island, Me	Sept. 10	35
1600	43	52	31	67	54	25	Northeast Matinicus	Sept. 8	33

[1] 1924.

SERIES E: Bottles Nos. 1701 to 1800; two every half mile along a line running 125° from Cape Elizabeth whistling buoy, for 25 miles, August 4, 1923.

No.	Set out						Where found	Date, 1923	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
1702	43	32	00	70	12	00	Beachwood, Me	Sept. 7	31
1712	43	30	35	70	09	10	Siasconset, Mass	Dec. 24	139
1720	43	29	27	70	6	54	Clifford's Cove, Long Island, Nova Scotia	Oct. 20	74
1721	43	29	10	70	6	20	4 miles southeast Seguin light, Me	Sept. 8	32
1726	43	28	36	70	5	12	Entrance Grand Harbor, New Brunswick, Nova Scotia	Nov. 26	111
1728	43	28	19	70	4	48	New River Beach, Charlotte County, New Brunswick, Canada	Oct. 22	76
1731	43	27	45	70	3	40	North Beach, Chatham, Mass	Dec. 6	121
1732	43	27	45	70	3	40	New Meadows River, Me	Sept. 14	38
1733	43	27	28	70	3	06	Mascabin Point light, New Brunswick, Canada	Oct. 21	75
1734	43	27	28	70	3	06	Pond Island, Casco Bay, Me	Oct. 1	55
1740	43	26	37	70	1	24	Shore of Round Pond Harbor, Me	Nov. 2	77
1763	43	23	23	69	54	36	Salmon River, St. Marys Bay, Nova Scotia	Nov. 5	90
1764	43	23	23	69	54	36	Centreville, Digby County, Nova Scotia	Oct. 9	63
1768	43	22	49	69	53	28	Bay of Fundy shore, Digby County, Nova Scotia	Oct. 10	64
1769	43	22	32	69	52	54	Comeau Cove, Digby County, Nova Scotia	Oct. 10	64
1773	43	21	58	69	51	46	Big Wood Island, Grand Manan, Nova Scotia	Oct. 2	56
1780	43	21	07	69	50	04	Bay of Fundy, Brier Island, Digby County, Nova Scotia	Nov. 4	79
1792	43	19	25	69	46	40	Metinic Island, Me	Oct. 10	64
1793	43	19	08	69	46	06	Sheepscot River, Me	Sept. 10	34

SERIES F: Bottles Nos. 1601 to 1700; two bottles every half mile along a line running 99° from Thatchers Island, Cape Ann, for 25 miles, August 9, 1923.

No.	Set out						Where found	Date, 1923	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
1635	42	36	22	70	19	23	Yarmouth Harbor, Yarmouth County, Nova Scotia	Oct. 18	60
1636	42	36	22	70	19	23	Port Maitland, Yarmouth County, Nova Scotia	Oct. 12	64
1645	42	36	02	70	15	58	Cockeritt Passage, Shelbourne County, Nova Scotia	Oct. 13	65
1648	42	35	58	70	15	17	15 miles north of Yarmouth Cape, Nova Scotia	Dec. 25	138
1672	42	35	10	70	7	05	East side Digby Gut, Nova Scotia	Nov. 2	85
1677	42	34	58	70	5	15	Dogs Bay, Roundstone West, County Galway, Ireland	[1] Jan. 2	------
1692	42	34	30	70	0	15	East of Preston Littlehampton, Sussex, England	[2] Sept. 25	------

[1] 1925. [2] 1924.

SERIES G: Bottles Nos. 1801 to 1900; two every half mile on a line running 73° from a point half a mile off the radio towers at South Wellfleet, Cape Cod, for 25 miles, August 16, 1923.

No.	Set out						Where found	Date, 1923	Interval
	Latitude			Longitude					
	°	′	″	°	′	″			Days
1815	41	56	03	69	52	40	Nauset Harbor, Mass	Sept. 12	27
1826	41	56	48	69	49	36	Nauset Lighthouse, North Eastham, Cape Cod, Mass	Aug. 18	2
1881	42	00	57	69	31	20	Eastern edge of Georges Bank, latitude 41° 50′, longitude 66° 0′	Oct. 14	59
1885	42	01	15	69	30	06	Bally Teique Bay, Kilnare Quay, County Wexford, Ireland	[1] Sept. 20	------
1892	42	01	42	69	28	15	Tiverton, Digby County, Nova Scotia	[1] Jan. 12	149

[1] 1924.

SERIES H: Bottles Nos. 1 to 85, placed in Nantucket and Vineyard Sounds in 1924, as follows:

1. On a line from Great Point, Nantucket Island, N. 10° W., running about one-half mile west of Handkerchief Shoal lightship to within about 1½ miles of the coast of Cape Cod. Bottles dropped approximately one-third mile apart. Bottle

No. 1 was dropped nearest Great Point at 11.17 a. m., August 4. Bottle No. 45 was dropped nearest the mainland at 12.45 p. m.

2. On a line from Succonesset Point to Cape Pogue. Bottle No. 46 was dropped nearest Succonesset Point at 10.17 a. m., August 5, while No. 67 was dropped nearest Cape Pogue at 10.59 a. m.

3. On a line from Pasque Island to Menemsha Bight. Bottle No. 68 was dropped nearest Pasque Island at 12.04 p. m., August 6, and bottle No. 85 was dropped nearest shore in Menemsha Bight at 12.38 p. m.

No.	Set adrift		Recovered	
	Date, 1924	Place	Date, 1924	Place
2	Aug. 4	From Great Point north 10° west ⅔ mile.	Oct. 4	Point Pleasant Beach, N. J.
3	...do	From Great Point north 10° west 1 mile	Sept. 29	1 mile east of Mecox station, Bridgehampton, Long Island, N. Y.
14	...do	From Great Point north 10° west 4⅔ miles.	Sept. 22	East Hampton, Long Island Beach.
19	...do	From Great Point north 10° west 6⅓ miles.	[1] Mar. 4	Eorabus, Bunessan, Mull, Argyle, Scotland.
27	...do	From Great Point north 10° west 9 miles.	Sept. 30	Lonelyville, Fire Island, N. Y.
28	...do	From Great Point north 10° west 9⅓ miles.	Oct. 7	About 72d Street, Holiday Beach, N. J.
31	...do	From Great Point north 10° west 10⅓ miles.	Sept. 29	Beach Haven, N. J.
37	...do	From Great Point north 10° west 12⅓ miles.	Aug. 22	In Bucks Creek, South Chatham, Mass.
38	...do	From Great Point north 10° west 12⅔ miles.	Aug. 20	Harwichport, Mass.
39	...do	From Great Point north 10° west 13 miles.	Aug. 7	1 mile west of Monomoy Coast Guard station (south of Chatham, Mass.).
41	...do	From Great Point north 10° west 13⅔ miles.	Aug. 11	Forest Beach, South Chatham, Mass.
42	...do	From Great Point north 10° west 14 miles.	Aug. 9	Hardings Beach light, Chatham Bay, Mass.
43	...do	From Great Point north 10° west 14⅓ miles.	Aug. 16	½ mile from Hardings Beach light, West Chatham, Mass.
44	...do	From Great Point north 10° west 14⅔ miles.	Aug. 9	Bucks Creek, South Chatham, Mass.
45	...do	From Great Point north 10° west 15 miles.	Aug. 10	South Chatham, Mass.
46	Aug. 5	From Succonesset Point south ⅓ mile	Aug. 26	4 miles southeast of Rose and Crown Buoy, Nantucket Shoals Mass.
47	...do	From Succonesset Point south ⅔ mile	Aug. 16	1 mile off Wiano Point, Cape Cod, Mass.
49	...do	From Succonesset Point south 1⅓ miles	Aug. 11	West side of Great Island Point, Hyannis Harbor, Mass.
50	...do	From Succonesset Point south 1⅔ miles	Aug. 10	Near Hyannis Lighthouse, South Hyannis, Mass.
51	...do	From Succonesset Point south 2 miles	Aug. 29	Mouth of Bass River, Cape Cod, Mass.
52	...do	From Succonesset Point south 2⅓ miles	Aug. 9	Between Marthas Vineyard and Succonesset Point, Mass.
53	...do	From Succonesset Point south 2⅔ miles	Aug. 18	West side of Hyannis Harbor, Mass.
55	...do	From Succonesset Point south 3⅓ miles	Aug. 10	West Beach, Hyannisport, Mass.
56	...do	From Succonesset Point south 3⅔ miles	Sept. 11	Bass River, Mass.
63	...do	From Succonesset Point south 6 miles	Aug. 31	Dennisport Beach, Cape Cod, Mass.
64	...do	From Succonesset Point south 6⅓ miles	Aug. 26	Foot of Morey Lane, Siasconset, Mass.
66	...do	From Succonesset Point south 7 miles	[2] Dec. 17	At entrance to Chatham Harbor, Mass.
67	...do	From Succonesset Point south 7⅓ miles	Nov. 10	1 mile west of the Green Hill Coast Guard station (R. I. ?).
68	Aug. 6	From Pasque Isle south ⅓ mile	Aug. 18	Northeast shore of Cuttyhunk Island, Mass.
69	...do	From Pasque Isle south ⅔ mile	Aug. 14	2 miles north of Woods Hole, Mass.
71	...do	From Pasque Isle south 1⅓ miles	Aug. 7	¼ mile northeast of Cedar Tree Neck, Vineyard Sound, Mass.
72	...do	From Pasque Isle south 1⅔ miles	Sept. 21	Extreme end of Tuckernuck Island, Mass.
74	...do	From Pasque Isle south 2⅓ miles	Sept. 22	Brant Beach, N. J.
76	...do	From Pasque Isle south 3 miles	Aug. 14	4 miles northwest of Vineyard Sound Lightship.
79	...do	From Pasque Isle south 4 miles	Aug. 27	Menemsha Bight, Vineyard Sound, Mass.
80	...do	From Pasque Isle south 4⅓ miles	Aug. 10	East Passage, Narragansett Bay, R. I.
81	...do	From Pasque Isle south 4⅔ miles	Sept. 29	1 mile north of Sea Isle City, N. J.
82	...do	From Pasque Isle south 5 miles	Sept. 30	Hereford Inlet, Anglesea, N. J.
83	...do	From Pasque Isle south 5⅓ miles	Aug. 11	Ribbon Reef, ½ mile west of buoy.

[1] 1926

[2] 1924.

SERIES I: Bottles Nos. 1 to 60, set adrift in Massachusetts and Cape Cod Bays, February 6 and 7, 1925, by the *Fish Hawk*, cruise No. 6. (For station record, see p. 1004.)

No.	Set out							Where found	Date, 1925	Interval
	Hour	Latitude			Longitude					
		°	′	″	°	′	″			Days
15	12.45 p. m.	42	12	00	70	23	30	Near radio station, Nantucket	June 14	128
22	2.50 p. m.	42	03	18	70	14	42	Fire Island Coast Guard station, N. Y.	July 4	87
25	3.40 p. m.	42	00	45	70	11	50	Beach, Provincetown, Mass.	Feb. 11	5
26	do	42	00	45	70	11	50	Pilgrim Heights, Mass.	Feb. 26	20
27	do	42	00	45	70	11	50	East end of breakwater, Provincetown, Mass.	Feb. 12	6
28	4.10 p. m.	41	58	12	70	10	48	Pickett Wharf, Provincetown, Mass.	Feb. 14	8
29	do	41	58	12	70	10	48	C. L. Birch's store, Provincetown, Mass.	Feb. 11	5
30	do	41	58	12	70	10	48	Can factory wharf, Provincetown, Mass.	do	5
32	4.40 p. m.	41	55	30	70	09	30	Beach at Provincetown, Mass.	Feb. 12	6
33	do	41	55	30	70	09	30	Beach at North Truro, Mass.	Feb. 11	5
34	5.35 p. m.	41	52	18	70	10	30	East Harbor, Provincetown, Mass.	do	5
35	do	41	52	18	70	10	30	Eastern cold-storage wharf, Provincetown, Mass.	do	5
36	do	41	52	18	70	10	30	Smiths Bathing Beach, Mass.	Feb. 12	6
37	6.00 p. m.	41	49	30	70	11	15	Provincetown Harbor, Mass.	Feb. 11	5
38	do	41	49	30	70	11	15	On beach, Provincetown Harbor, Mass.	Feb. 14	8
39	do	41	49	30	79	11	15	Provincetown Harbor, Mass.	Feb. 12	6
40	6.52 p. m.	41	52	27	70	15	24	North Truro Beach, Cape Cod Bay, Mass.	Feb. 17	11
42	do	41	52	27	70	15	24	Bay shore, North Truro, Cape Cod, Mass.	Feb. 22	16
43	7.15 p. m.	41	56	00	70	18	30	Beach Point, Provincetown Harbor, Mass.	Feb. 23	17
44	do	41	56	00	70	18	30	Provincetown Harbor, Mass.	Feb. 18	12
74	10.45 a. m.	42	07	18	70	36	36	29 miles from Eastern Point, Stellwagen Bank	Feb. 16	10
78	11.00 a. m.	42	09	30	70	38	15	Surfside, south shore, Nantucket	June 30	144
85	12.50 p. m.	42	16	06	70	42	30	Freeport, Digby County, Nova Scotia	July 2	146
89	1.10 p. m.	42	18	15	70	44	00	28 miles east-southeast from Thatchers Island		

Series J: Bottles Nos. 91 to 101, set out in Ipswich Bay and off Cape Ann by the *Fish Hawk*, April 7, 1925.

No.	Set out							Fish Hawk station	Where found	Date, 1925	Interval
	Hour	Latitude			Longitude						
		°	′	″	°	′	″				Days
95	3.20 a m.	42	49	30	70	40	00	23	¼ mile west of Race Point, Cape Cod	Apr. 21	14
96	do	42	49	30	70	40	00	23	¼ mile southeast of Race Point, Cape Cod	Apr. 24	17
97	4.30 a. m	42	46	00	70	40	00	21	2 miles off Cutler, Me.	July 21	105
99	6.10 a. m	42	38	00	70	33	00	29	2 miles north of Brant Rock, Mass., Coast Guard station	Apr. 29	22

Series K: Bottles Nos. 102 to 141, set out in pairs by the *Fish Hawk* in Massachusetts Bay, May 20 to 22, 1925, cruise No. 13 (p. 1004).

No.	Set out							Fish Hawk station	Where found	Date, 1925	Interval
	Hour	Latitude			Longitude						
		°	′	″	°	′	″				Days
103	6.41 a. m.	42	18	15	70	44	00	17	Dennisport, Mass.	June 6	17
106	9.10 a. m.	42	16	54	70	30	30	18A	3 miles northwest of Race Point Light, Cape Cod	May 26	6
108	11.15 a. m.	42	05	00	70	35	00	14	1¼ miles north of Pamet River Coast Guard station, Cape Cod.	May 30	10
109	do	42	05	00	70	35	00	14	Coast Guard station, Provincetown, Mass.	May 25	5
112	3.10 p. m.	41	56	00	70	18	30	6A	Race Point, Mass., Coast Guard station	June 1	12
113	do	41	56	00	70	18	30	6A	South Beach, Edgartown, Mass.	July 24	65
114	4.45 p. m.	41	49	30	70	11	15	7	6 miles east of Gurnet Light, Plymouth, Mass.	May 29	9
115	do	41	49	30	70	11	15	7	South Truro, Mass.	May 26	6
117	5.55 p. m.	41	55	30	70	11	15	6	5 miles west of Race Point, Cape Cod	May 31	11
118	5.50 a. m.	42	05	30	70	17	00	4	Nauset Beach, near Coast Guard station, Eastham, Mass.	July 12	52
120	7.00 a. m.	42	09	30	70	19	30	3	75 miles southeast by south from Cape Cod Light	June 12	22
126	12.55 p. m.	42	23	30	70	15	30	32	1¼ miles West of Race Point Coast Guard station, Cape Cod.	May 27	6
127	do	42	23	30	70	15	30	32	2 miles off Peaked Hill bar, Cape Cod	do	6
136	7.10 a. m.	42	30	15	70	43	15	36	Marblehead Neck, Mass.	July 15	54
137	do	42	30	15	70	43	15	36	Pea Island, Nahant, Mass.	June 1	10
139	8.25 a. m.	42	28	00	70	48	00	37	¼ mile east of Tinkers Island, Marblehead, Mass.	May 31	9
140	9.20 a. m.	42	24	15	70	52	15	38	Lynn Beach, Mass.	May 27	5
141	do	42	24	15	70	52	15	38	Long Island, Boston Harbor, Mass.	May 28	6

SERIES L: Bottles Nos. 1901 to 1941, set out by H. C. Stetson on a line running 75° for 10 miles from Dry Salvages Beacon, off Cape Ann, 1 bottle every one-fourth mile, April 19, 1926. First bottle put out at 7 a. m.; last bottle at 9.11 a. m.

No.	Distance out from starting point	Where found	Date, 1926	Interval
	Miles			*Days*
1904	1	1 mile east of Madakket Coast Guard station, Nantucket Island	June 30	70
1907	1¾	Monomoy Point, Mass	June 7	49
1911	3	South shore of Marthas Vineyard, between Gay Head and Edgartown	July 4	74
1913	3¼	2 miles south of Chatham Light, Mass	May 30	30
1915	3¾	1 mile north of Pamet River Coast Guard station, Cape Cod	June 26	66
1916	4	1 mile north of Old Harbor Coast Guard station, Chatham, Mass	May 27	38
1917	4¼	Beach near Hummock Pond, Nantucket	June 2	44
1918	4½	South shore, Nantucket, near radio station	Sept. 8	142
1919	4¾	1½ miles west of Race Point Coast Guard station, Cape Cod	May 21	32
1922	5¼	Lepreau Harbor, Charlotte County, New Brunswick	July 24	94
1923	5¾	Harts Island, Port Clyde, Me	July 15	85
1927	6¾	12 miles below Digby Gut, Nova Scotia, 1 mile offshore	Aug. 16	119
1937	9¼	10 miles west of Brier Island, Digby County, Nova Scotia	July 3	73
1941	10	¼ mile from Weymouth Light, Digby County, Nova Scotia	July 7	77

SERIES M: Bottles Nos. 1942 to 1970, set every one-half mile on a line from light buoy off Manomet Point, Mass., to Wood End, Provincetown, by Henry C. Stetson, April 21, 1926. First bottle put out at 11 a. m.; last bottle at 3.30 p. m.

No.	Distance set out from Manomet	Where found	Date, 1926	Interval
	Miles			*Days*
1945	1½	Wood End Coast Guard station, Provincetown	May 22	31
1946	2	Provincetown Bay, Provincetown, Mass	May 3	12
1949	3½	Wood End station, Provincetown, Mass	Apr. 28	7
1953	5½	Provincetown Bay, Mass	June 12	52
1956	7	3 miles north of Wood End station, Provincetown, Mass	Apr. 28	7
1960	9	⅛ mile south of Race Point Light, Cape Cod	June 9	49
1961	9½	Race Point Light, Provincetown, Mass	Apr. 23	2
1963	10½	Race Point Light station, Provincetown, Mass	May 10	19
1964	11	Near Race Point Light, Provincetown, Mass	May 2	11
1965	11½	2 miles north of Wood End Light, Provincetown, Mass	do	11
1967	12½	1 mile south of Race Point, Provincetown, Mass	May 12	21
1968	13	Wood End Run, Provincetown, Mass	May 15	24

SERIES N: Bottles Nos. 1971 to 1980, set out by Henry C. Stetson every one-half mile on a line running 244° for 5 miles from a point 1 mile west of the mouth of Pamet River, Truro, Mass., April 21, 1926. Outer bottle set out at 3.55 p. m.; innermost bottle at 4 p. m.

No.	Distance set out offshore	Where found	Date, 1926	Interval
	Miles			*Days*
1974	4	½ mile south of Wood End Coast Guard Station, Provincetown, Mass	Apr. 24	3
1975	3½	1 mile off Church Point Light, St. Marys Bay, Digby County, Nova Scotia	July 9	79
1978	2	Off Wood End Light, Provincetown Mass	Apr. 29	8
1980	1	Seeleys Cove, 5 miles west of Beaver Harbor Light, Charlotte County, New Brunswick	July 22	92

Series O: Bottles Nos. 1952 and 1981 to 2000, set out on July 18, 1926, by T. E. Graves, on a line running 107° from Cape Neddick, Me., for 9 miles, 1 bottle every one-half mile. First bottle (No. 1952) put out at 8.17 a. m.; last bottle (No. 2000) at 10.44 a. m.

No.	Distance set out from Cape Neddick	Where found	Date, 1926	Interval
	Miles			*Days*
1982	1½	Kenwood Bridge, Salem, Mass	Aug. 4	17
1985	3	10 miles southeast by south from Thatchers Island, Mass	Aug. 3	16
1987	4	do	do	16

GENERAL DISCUSSION OF THE RECOVERIES

With the Bay of Fundy experiments as a guide, it was natural to expect a considerable number of the bottles released in the Gulf of Maine on the several lines off Mount Desert, Cape Elizabeth, and Cape Ann, in 1922 and 1923, to be picked up in the Massachusetts Bay region. This, however, did not prove to be the case. Not a single bottle from any of these series has been found anywhere between Cape Ann and the southern elbow of Cape Cod, and only five of them south of Kennebunkport. It is therefore evident that the dominant surface drift was not the same in the summers of 1922 and 1923 as it was in 1919, but drifts of the 1919 type were recorded for series L and O, as described below.

The most striking aspect of the experiments carried out in all these summers is that more than 30 per cent of all the recoveries of bottles put out north of the southern angle of Cape Cod have been from the Bay of Fundy and Nova Scotia, which (if these were the only data available on the circulation of water in the gulf) would obviously suggest a drift from south and west to north and east. However, as we have just seen, the bottle drifts of 1919 and of 1926, on the contrary, point to an anticlockwise current skirting the shores of the gulf from northeast to southwest, and salinities (p. 910), temperatures (p. 918), and the distribution of the plankton (p. 923) all point in the same direction. It therefore becomes necessary to reduce these apparently contradictory lines of evidence to a rational order, which may best be done by analyzing the results for the years 1922 to 1926 regionally, not chronologically, to test whether they prove consistent, one with the other. The dominant sets of the surface water are shown rather clearly for the southwestern part of the gulf by the lines off Cape Ann, in Massachusetts Bay, off Cape Cod, and in Vineyard and Nantucket Sounds. These, therefore, may be considered first, leaving until later the study of the more puzzling drifts of the bottles set out in the northern side of the gulf.

SOUTHWESTERN SERIES

These bottles were set out off Cape Ann, in Massachusetts Bay, off Cape Cod, and to the southward of the latter.

The Cape Cod line of July, 1922 (line B), proved, in some ways, the most instructive of all, for out of these 600 bottles, 131, or 22 per cent, were picked up within

4 months. The line may be divided into three sections, according to the localities of recovery: First, an inner section, from Cape Cod across the mouth of Nantucket Sound and skirting the easterly edge of Nantucket Shoals; second, a middle section, from the shoals out nearly to the edge of the continent; and third, the outer end of the line to the seaward of the continental edge.

Ten bottles out of the 250 set out along the inner section were picked up to the eastward, three of them on the Nova Scotian shore of the Bay of Fundy, one on the northeastern part of Georges Bank, and five (after short drifts) in the south channel and along the northwestern side of Georges Bank (fig. 174).[66] This last group of recoveries is especially instructive as evidence that the surface water to the south and southeast of Cape Cod was setting in a southeasterly direction at the time. Bottle No. 362, picked up 40 miles to the southeast of the place of its release, after 5 days' drift, and Nos. 396 and 405, found 30 miles away after 8 days, can hardly have diverged from a direct line except to follow the spiral tracks induced by the veering tidal currents of this region, unless the dominant set was more rapid at the time than other experiences in the gulf would suggest.[67] A southeasterly set is also indicated in this general region by the current measurements carried out by the United States Coast and Geodetic Survey (p. 864).

The uniformity of these southeasterly drifts makes it likely that the bottles that went from the inner end of line B to the eastern end of Georges Bank and to Nova Scotia also drifted in a southeasterly direction at first, veering to the eastward—i. e., anticlockwise.

It seems that this inner section of line B followed the boundary of demarkation between this southeasterly set and another drift directed more to the southward from the mouth of Nantucket Sound, veering westward past Nantucket Shoals, because 20 bottles from this section were picked up along the southern coast of New England. The fact that current measurements show a general southeasterly set over Nantucket Shoals and a summer set to the west and northwest at the lightship a few miles farther south, makes it more likely that these bottles rounded the shoals than that they crossed the latter.

It is a question of considerable interest whether 11 bottles, spaced across the eastern entrance to Nantucket Sound, which were picked up along the south shores of Nantucket, Marthas Vineyard, and of New England between Buzzards Bay and and Block Island, drifted directly westward through Nantucket and Vineyard Sounds or whether they also traveled southward around Nantucket Island and Shoals. Of course, a positive answer can not be given; but it seems hardly conceivable that some of them would not have been picked up afloat in the sounds or stranded along shore there if they had gone through, because these beaches are thronged with vacationists. Actually, however, not one of the bottles from line B was found along the northern coast of the sounds, and only one of them on the northern shore of Nantucket, 159 days after it was set afloat. One, however, after 30 days afloat, was found 1 mile inside Gay Head at the western end of Marthas Vineyard, where many species of tropical fishes have been recorded in summer. Thus, it seems almost certain that

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[66] One bottle from this section went to France.

[67] Bottle No. 510 was reported on the northwest slope of Georges Bank, 50 miles from where it was set out, within 3 days. This ostensible drift is so rapid, however, that some error in the reported locality seems probable.

this group of bottles went out around Nantucket.[68] Bottle No. 536 journeyed to the south shore of Marthas Vineyard (85 miles) at a rate of at least 4 miles per day.

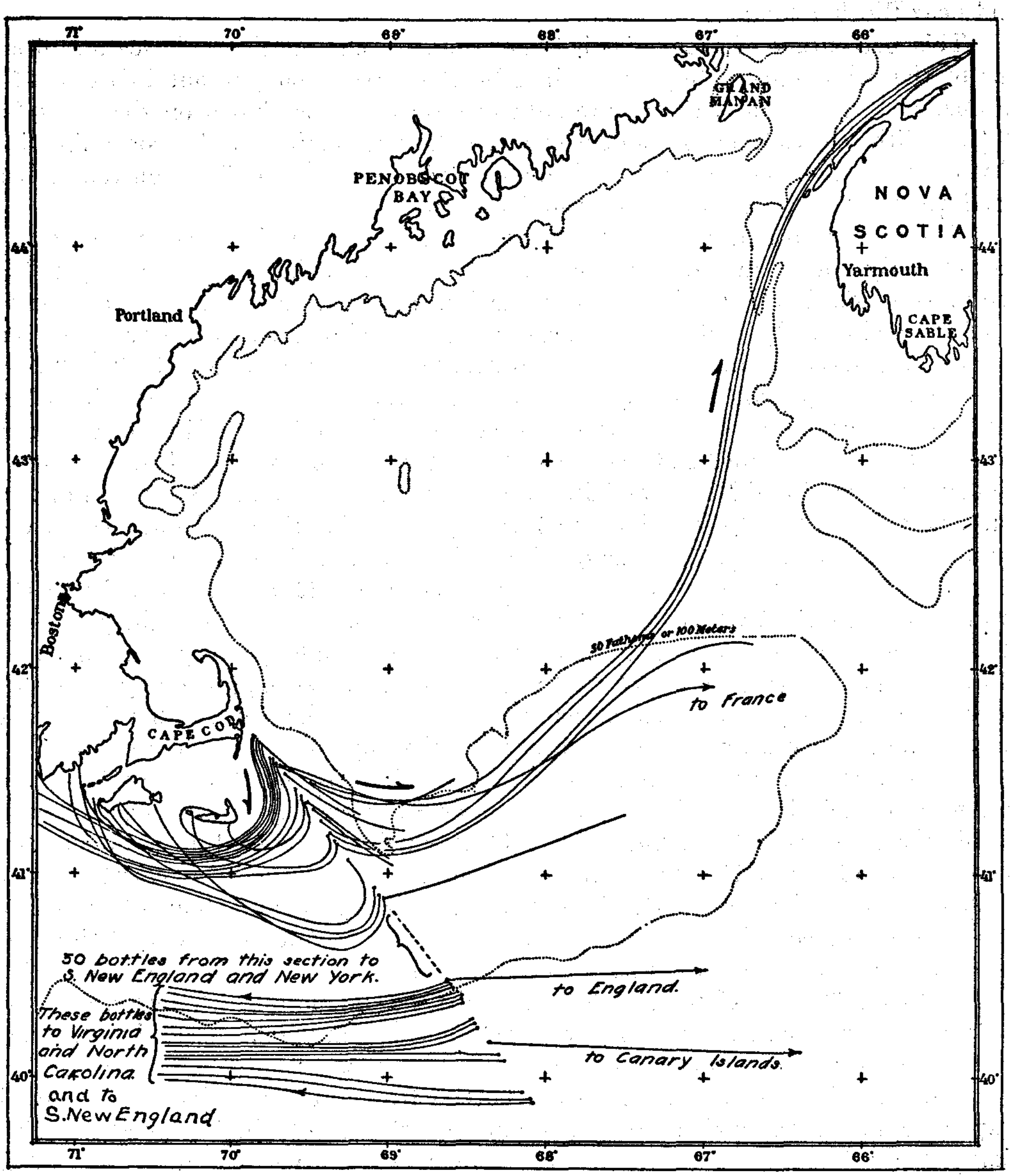

FIG. 174.—Assumed drifts of representative bottles recovered from line B, set out off Cape Cod, July 6 to 8, 1922. ●, place of release.

The mid-section of line B (lat. 40° 50′ to lat. 41° 30′) was clearly involved in this same set, veering clockwise around Nantucket Shoals, because 50 of these bottles out of a total of 103 were picked up along the shores of southern New England, from

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[68] The assumed routes for this group of bottles are laid down on the chart without reference to Nantucket Shoals. Actually, however, the complex tidal currents among these banks and through the channels between them must give a very circuitous route to any flotsam in that region.

Nantucket westward, and along the eastern half of Long Island, New York, the great majority on the south shore of Marthas Vineyard, at the mouth of Buzzards Bay, and near Block Island.

This percentage of recoveries is larger than for any considerable section of any one of the other lines along which drift bottles have been put out in the Gulf of Maine, so large, in fact, that representatives only can be shown on the chart (fig. 174). With the recoveries condensed in so short a section of the coast line, it is obvious that these bottles came within the grip of a very definite current setting northward and inshore, probably around the shoals.

The alteration along line B, from westerly drifts at the inshore end to easterly and westerly both from the next section of 40 miles, and then to westerly again from the mid-section, is clear evidence that the line followed the boundary between the Gulf of Maine eddy and the clockwise drift around the shoals to the west just stated, locating the southern boundary of the former at about latitude 40° 50′.

This westerly drift certainly involved the water right out to the edge of the continent, because 22 bottles from the outer section of line B (including the outermost of all, set adrift 40 miles out from the 200-meter contour) were picked up between Nantucket Island and Fire Island Beach on Long Island, N. Y. Seventeen of these outer bottles (10 from just inside and 7 from just outside the continental edge) were found on the North Carolina beach, a few miles north of Cape Hatteras,[69] after time intervals averaging 85 days (73 to 112 days). The mean distance traveled by this last group of bottles (if they followed a straight line) is about 410 miles—slightly longer by their probable route—giving a minimum rate of nearly 5 miles per day. It is probable, also, that the time intervals between the dates of setting out and recovery correspond very closely to the periods when actually afloat, because the sector of beach on which they stranded is continuously and closely patrolled by the Coast Guard stations.

Some further light is thrown on the tracks that the bottles of this last group followed on their journey, by recoveries set adrift a few days later along a line (C) running southeasterly from New York, 111 of which were picked up between Delaware Bay and Cape Hatteras. Most of those that reached the North Carolina coast from the outer part of this line were spaced from a point about 45 miles from the New Jersey coast out to a point some 40 miles beyond the edge of the continent, as marked by the 100-fathom contour. It is therefore fair to assume that the bottles from the Cape Cod line that drifted farthest south likewise passed Delaware Bay within a few miles (one way or the other) of the continental edge, where they would have intersected the New York line.

The fact that so many of the other bottles from the same outer section of the Cape Cod line drifted inshore, to strand along southern New England, makes it likely that this whole group of bottles set northwestward, in over the outer part of the continental edge at first, and then separated, some veering to the westward and southwestward along the outer part of the shelf, others turning northward toward the coast. There must also have been a rather direct drift of surface water in that direction from the offing of Nantucket Shoals, and so in toward the land, at the time, for if the bottles that traveled that route had gone far west before turning

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[69] Scattered from False Cape to a point 9 miles north of Hatteras Light.

north the New York line would have been involved in this same drift and so have stranded along the coast of Long Island to the east of Fire Island lighthouse, where only three of them actually were found.

The combined evidence of these Cape Cod and New York lines thus points to a dominant movement of the surface water along the edge of the continent, westward and southward from the offing of Nantucket to Cape Hatteras, but complicated by a clockwise eddy movement in toward the land west of Nantucket Shoals, just where flotsam from the so-called "Gulf Stream" (gulf weed and various tropical animals) most often drifts in to the coast. No such tendency for the surface water to set inshore from the outer part of the continental shelf is reflected in the drifts to the west of this, however, not a single bottle from the Cape Cod line having been found between New York and Chesapeake Bay, though bottles from the New York line were picked up all along this 250-mile sector.

No further discussion of the bottles set out off New York is called for here, as they do not immediately touch the Gulf of Maine, except to emphasize that neither they nor the Cape Cod line afford any evidence whatever of surface water entering the gulf around Nantucket from the southwest. It has long been known that the southern angle of Cape Cod marks a rather abrupt faunal division between the waters of Nantucket and Vineyard Sounds, on the one hand, and the more boreal Gulf of Maine, on the other. It is obvious that a division of this sort, with no change of latitude, is associated with the nontidal circulation of the water.

It was to check the evidence of the drifts from line B and measurements with current meters (p. 864) pointing to a set of water outward from the eastern end of Nantucket Sound, and so toward the southeast, that lines H (p. 875) were set out along three sections of the sounds during August, 1924.

Thirty-seven of these 85 bottles have been recovered within the sounds, along the outer shores of Nantucket, and still farther west, but not one of them within the limits of the Gulf of Maine.

The drifts from the western end of Marthas Vineyard (Pasque Island to Menemsha Bight) may be passed over briefly. Eleven of these were picked up—1 on Cuttyhunk Island, 2 in Vineyard Sound, 1 on Tuckernuck Island, 1 within Buzzards Bay, 2 at the mouth of the latter, 1 in Narragansett Bay, and 3 on the Rhode Island shore (fig. 175). It is not easy to reconstruct the probable paths of all of these.

The series was set adrift on the first of the ebb, which sets westward here through Vineyard Sound and northward from the latter through the "holes" between the Elizabeth Islands into Buzzards Bay. It is probable that the bottles found in Buzzards Bay and on Cuttyhunk went north through Quick's Hole, because they were put out close to Pasque Island at about high water and would soon have been carried in that direction by the ebb. If this line had been put out on the flood instead of at the beginning of the ebb it would probably have been carried far enough up the sound before the tide changed to come within the easterly set that appears to dominate Nantucket Sound. Actually, however, most of these bottles must have drifted westward for the first 5 or 6 hours, carrying them about to the mouth of Vineyard Sound, where a division evidently took place. Two bottles from the northern end seem to have been carried back into the sound by the next flood, one of them to be picked up two days later on the Marthas Vineyard shore, 6 miles to the east of where it was put out, the other on Tuckernuck Island, between Nantucket and Marthas Vineyard, after 46 days.

The others, from the southern end of this line, seem to have been carried far enough out of the sound on the first ebb to escape the next flood back again. The two that were picked up at the mouth of Buzzards Bay must have drifted on a comparatively direct route, for one was picked up after five and the other after six days. Evidently they came within the sweep of the Buzzards Bay tides. The bottles that went to New York and New Jersey must have escaped this. The one that was picked up at the entrance to Narragansett Bay only five days after it was put out evidently followed a route directly westward, making it a fair assumption that the three others set afloat close by, which went to New Jersey, also traveled via the same route, paralleling the coast.

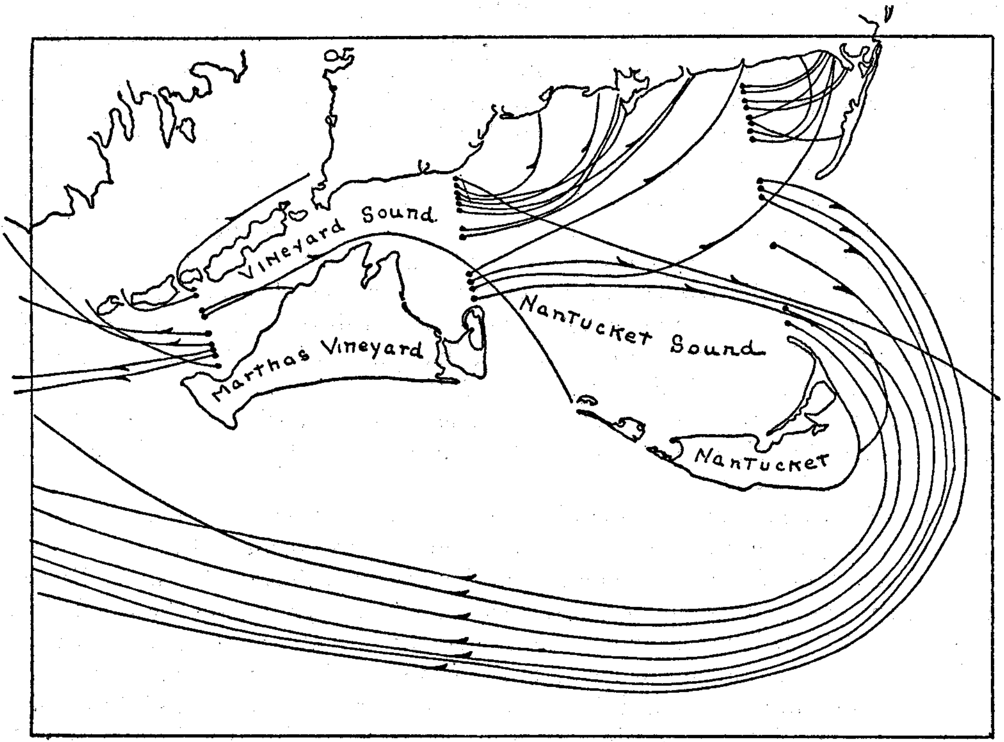

FIG. 175.—Assumed drifts of representative bottles recovered from lines H, set out in August, 1924. ●, place of release

It would be an instructive experiment to put bottles out on this same line early on the flood tide, so that they would journey eastward, up the sound at first, not out of it, so to determine what net movement results from tides whose velocity (1.7 to 2.5 knots at strength) is so great that "a certain part of the water, at least, travels a distance of one-half or more of the length of Vineyard Sound during a single phase of the tide." (Sumner, Osburn, and Cole, 1913, p. 36.) The earlier current tables published by the United States Coast and Geodetic Survey (Coast Pilot, 1912, Appendix I) indicate a net westerly drift of the water along the axis of Vineyard Sound at a rate of about ·2 miles per 24 hours, the easterly movement averaging about 3½ miles during the flood, the westerly ebb about 4½ miles. More recent information, however, does not substantiate this, ebb and flood being given as approximately equal along the axis of the Sounds in the current tables for 1924 (United States Coast and Geodetic Survey, 1923); and the fact that considerable quantities of gulf weed so often drift into Vineyard Sound and through into Nantucket Sound in the summer season points rather to a net movement inward into the former from the westward.

The returns from the line next to the east (Succonnesset Point to Cape Pogue; fig. 175) are consistent with a dominant set from west to east along the southern side of Nantucket Sound, because all but one of the recoveries were to the eastward of where the bottles were set out—9 of them from points along its northern shores as far as Chatham; 1 close to Rose and Crown Buoy outside the sound, about 11 miles east of Nantucket Island; 1 from the southeast shore of Nantucket; and 1 from the coast of Rhode Island. Bottles from all parts of the line stranded along the north shore, and the drifts that went out of the sound were from both ends of the line (the bottle picked up near Rose and Crown Shoal was thrown out closest to Succonnesset). This suggests that all traveled eastward at first, as would naturally happen, as they were put out one to two hours after low water; but this first flood, running at an average rate of about 1 knot, can only have carried these bottles 4 or 5 miles east.

It is possible, of course, that the bottles that went from this line to the eastern side of Nantucket and to Rose and Crown Shoal passed out of the sound via the Tuckernuck Channel; but the more direct route eastward is the more probable when these drifts are studied in connection with the line put out across the eastern end of the sound.

Fourteen bottles from this line were recovered, 6 of which (set out abreast the channel between Nantucket and Monomoy) made long journeys to Long Island, New York, and New Jersey, while 8 bottles set out behind Monomoy Island were picked up along the coast near by, between Harwichport and Monomoy. This division, and the fact that the only bottles from this line that were recovered within the sound were those just mentioned, makes it fairly certain that the bottles that made the long journeys did not go westward through the sound, but drifted eastward out of the latter at first and then veered clockwise to the southward and so around Nantucket by the same general route followed by bottles set out off the mouth of the sound in 1922 (line B, p. 880), and so continued westward, paralleling the coast, to the points where they were finally picked up.

This division between the drifts followed by the bottles from the southern and northern parts of the line clearly reflect a tidal difference. All were put out two to three hours before high water; but while the first group was carried eastward by the flood and out of the sound, the second group was caught up in the current flooding northward into Chatham Roads. The fact that so many then stranded there, instead of coming out again with the ebb, and that so many bottles from the line next to the west were found along the northern shore of the sound, shows that the bight inclosed between Monomoy Point (with its submarine extension in Handkerchief Shoal) and the south shore of Cape Cod is the site of a subsidiary anticlockwise eddy, as might be expected from the trend of the coast and from the contour of the bottom.

The combined evidence afforded by the drifts from the two lines last discussed points unmistakably to an easterly set as dominating the southern side of Nantucket Sound, with a net movement of the surface water out through the channel between Great Point and Monomoy. The time intervals for the bottles picked up at Rose and Crown Shoal and on the east shore of Nantucket (21 days in each case) show a daily rate of at least 1½ to 2 miles in this direction at the time.

With none of the bottles from Nantucket Sound reported within the Gulf of Maine, but abundant evidence of drifts veering to the south and west around Nantucket Island and Shoals, it is established with reasonable certainty that the outflow from Nantucket Sound usually shares in the clockwise eddy movement away from the gulf, which involved the water to the southeast of Cape Cod in 1922 (p. 880) and which is indicated by the measurements made of the currents along the eastern side of Nantucket Shoals (p. 864).

The fact that three bottles set out in Nantucket Sound in 1924 were picked up in New Jersey, whereas none of the bottles set out abreast the mouth of the sound in 1923 were reported so far west, suggests that those that passed eastward out of the sound in 1924 then drifted far enough southward to become involved in the drift followed by the bottles put out on the middle section of the Cape Cod line in the year before. An interesting annual difference thus appears in this respect.

If this general type of circulation prevails as constantly from year to year and throughout the summer season, as the bottle drifts suggest, it goes far to explain the fact that tropical fishes, planktonic animals, and floating plants (notably gulf weed), which are so commonly swept from the "Gulf Stream" into Vineyard Sound, only exceptionally enter the gulf around Cape Cod. Passing out of Nantucket Sound to the eastward by the same route followed by the drift bottles, their course would then veer to the southward and so away from the gulf, not into the latter.

An earlier paragraph, the reader will recall, points out that several bottles from the inner (northern) end of line B, set out of Cape Cod in July, 1922, were carried eastward into the Gulf of Maine, though the majority were swept away from the gulf, locating the division between these two circulating movements (p. 882).

Series G was set out normal to the coast, about midway of Cape Cod, in August, 1923 (p. 875), in the hope of throwing more light on the southern side of the eddying circulation that dominates the surface waters of the Gulf of Maine. Only 5 out of the 100 have been recovered, this being the lowest percentage of recoveries for any of the lines. Two of them, put out, respectively, 4 and 6 miles from the land, were picked up at Nauset near by, one within 2 days after it was set adrift. One bottle, set afloat about 20 miles out at sea, was found 2 months later (October 14) floating on the eastern edge of Georges Bank (fig. 176); one launched 5 miles farther out was reported 5 months later from Tiverton, Digby County, on the Nova Scotian shore of the Bay of Fundy, near its mouth; and a fifth, also from the outer end of the line, picked up in Ireland in September a year later, completes the brief list (p. 875).

Evidently the outer bottles on this line (but not the inner) took part in a drift of the same sort as carried several bottles, set out southeast of Cape Cod in 1922, across to the eastern part of Georges Bank, to the Bay of Fundy, and to France (fig. 174), so that a set in this direction is to be expected in the southern side of the gulf in summer.

The measurements taken of the currents in the region of Georges Bank (p. 865; fig. 173) suggest that this group of bottles held to the northward of the shoal part of Georges Bank (Georges and the Cultivator Shoals) in their journey, and that a separation of the tracks evidently occurred to the eastward of the latter, some of the bottles then veering southward across the eastern side of Georges Bank, where one was recovered from each year's series (1922 and 1923) 96 and 59 days, respectively, after release.

The two bottles (one from each year's series) that went from close to Cape Cod to Europe (one to France, the other to Ireland, after a year's journey) probably followed much this same route, continuing on out to sea until they came within the influence of the general North Atlantic drift. Bottle No. 543, which was set out in the South Channel on July 7, 1922, and picked up just south of Georges Shoal 35 days later, was probably caught up in the tidal circulation over that shoal ground.

These Georges Bank drifts are good evidence that the bottles that went to the Bay of Fundy from the two Cape Cod lines (B and G; figs. 174 and 176) likewise skirted the northern side of the banks, continuing eastward until they became involved in the current setting northward into the eastern side of the gulf, which has been developed by Mavor (1922) from Dawson's measurements of currents (p. 861; fig. 173). The Bay of Fundy would then be their most likely destination; and the fact that they stranded on its Nova Scotian shore, just as did several of the bottles that Mavor set out at the mouth of the bay in 1919 (p. 868; Mavor, 1922), makes it likely that they, too, drifted in close along its southern side.

The three bottles that drifted from the offing of Cape Cod (line B) to the Bay of Fundy in 1922 were picked up after intervals, respectively, of 82, 102, and 105 days—an average of 97 days. Their probable route (figs. 174 and 176) being about 300 miles, a daily journey of slightly more than 3 miles is indicated. An interval of 59 days for bottle No. 1881, set out off Cape Cod on August 7, 1923, and picked up on the eastern edge of Georges Bank, points to about this same rate as probable; but bottle No. 435, from the Cape Cod series of the year previous, was not picked up on the eastern part of Georges Bank until 96 days after it was set out, though its journey along the general route it may be assumed to have followed was no longer. Another bottle from the same section of this same Cape Cod line was found on the western slope of Georges Bank, only about 50 miles distant from where it was set adrift, after it had been afloat for 88 days. It would be interesting to know whether it had circled to and fro over the banks during that long period. The only bottle from the Cape Cod line of 1923 (line G) that was reported from the Bay of Fundy was either longer afloat or lay longer on the shore before it was noticed, the interval between its release and recovery being 149 days, or less than 2 miles per day.

RECOVERIES FROM THE CAPE ANN AND MASSACHUSETTS BAY LINES

Only 7 of the 100 bottles set out off Cape Ann in August, 1923 (line F; p. 875), have ever been heard from. Five of these were found scattered along the Nova Scotian coast of the gulf and of the Bay of Fundy from Cockerwit Passage, in Pubnico Bay (near Cape Sable), to Digby Gut, and two went to Europe (fig. 176). Time intervals of 65 days (between release and recovery) to Pubnico, 60 days to Yarmouth, 64 days to Port Maitland, and 85 days to Digby Gut suggest a somewhat more direct route to Nova Scotia than was followed by the Cape Cod series of the year previous, because it is not likely that they traveled more than 3 or 4 miles per day until they approached Nova Scotia, where their daily rate may have increased to 5 to 6 miles (p. 867; fig. 173). The probable tracks laid down on the chart (fig. 176) are based on an assumed rate of about 3 miles per day, corresponding to the bottles that drifted from the Cape Cod line (line B) to the Bay of Fundy in 1922 (p. 887).

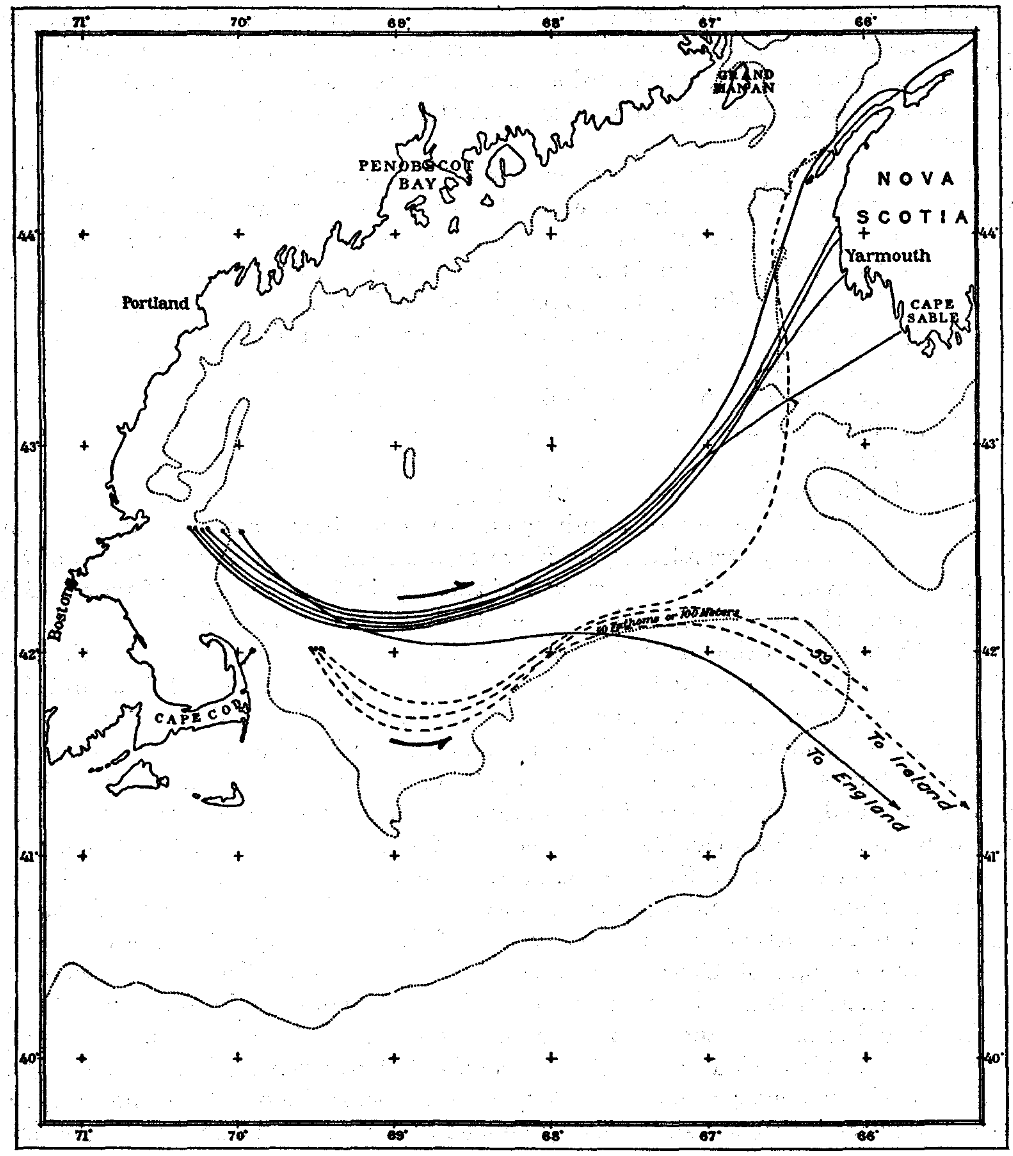

FIG. 176.—Assumed drifts of bottles recovered from lines F (solid curves) and G (dotted curves), set out off Cape Ann and Cape Cod, August 9 and 16, 1923. ●, place of release

If these drifts from the offing of Cape Ann to Nova Scotia stood alone, it would be impossible to tell whether their tracks diverged to the left of the direct line along the coast or to the right across the southern side of the basin. Comparison, however, with the bottles that went to the same general destination and eastward along Georges Bank from the Cape Cod lines (figs. 174 and 176) makes the second alternative much the more likely; and when we add the fact that not a single bottle from any of these three lines has ever been found along the coast between Cape Cod and the Bay of Fundy, contrasting with the number of recoveries scattered around the southern and eastern peripheries of the gulf from Georges Bank to the Bay of Fundy, the anticlockwise movement from the offing of Massachusetts Bay around the southern side of the basin and along its offshore rim, as indicated on the charts, seems fully demonstrated for the summers of 1922 and 1923.

The small number of recoveries from the Cape Ann line shows that only those that kept farthest north on this eastward journey came within the influence of the veering drift toward Nova Scotia. This is still more certainly true of the bottles set out off Cape Cod in 1923 (line G). To all intents and purposes these were entirely south of this set, for only odd ones among them were caught up by it. Such of the bottles as dispersed farther to the south from both these lines no doubt drifted to the Georges Bank region, and so, probably, out into the open Atlantic, either circling around the eastern end of the bank or crossing it, probably by the same tracks as were followed by the bottles that went to Europe. The fact that all the recoveries from outside the Gulf of Maine, for the Cape Cod and Cape Ann lines of 1923, were from the other side of the Atlantic, contrasting with the large number of bottles that went west from the line south of Cape Cod in 1922, is sufficient evidence that the eddy movement that carried the latter involved only the western part of Georges Bank at the time. In short, bottles from these lines, which drifted out of the Gulf of Maine in 1923, did so in a southeasterly direction across the eastern end of Georges Bank, traveling to the northward and eastward of its shoal ground.

Of course, it is possible that bottles found along western Nova Scotia after long intervals—say 100 or more days—may have followed this same route at first but then have been caught by an indraft through the Eastern Channel (p. 866). However, we have no positive evidence of this, and the chance that any bottle would be involved in the set toward Nova Scotia after it had once drifted south of latitude 42° is evidently very slight.

It is interesting to find that the bottles that drifted from west to east across the southern side of the gulf from the Cape Cod and Cape Ann lines tended to go far up the Bay of Fundy in 1922, but stranded near its mouth and along the Nova Scotian coast to the southward in 1923. Apparently the northerly set, which dominates the eastern side of the gulf, hugged that coast more closely in the one year than in the other, perhaps reflecting the prevalent winds at the time; but a difference of this sort is trivial, contrasted with the uniformity of these drifts and of those to the eastern part of Georges Bank, just discussed.

In 1919, the reader will recall, bottles from the Bay of Fundy stranded in Cape Cod Bay, marking a set into the latter; but in 1923 the Cape Ann line, by contrast, showed a drift past the mouth of Massachusetts Bay, not into the latter, proving a periodic variation, with the dominant movement following around the coast line of the bay in some summers and passing it as a sort of back water at other times. It was in the hope of throwing further light on this secular alternation, especially in its bearing on the involuntary migrations of fish eggs and larvæ, that series I and K were set out in the bay in February and May, 1925, and series L, M, and N in April, 1926 (p. 877).

Twenty-three (26 per cent) of the February series of 90 bottles have been recovered. Recoveries from bottles set out off the Plymouth shore were distributed as follows: One (No. 74) from Stellwagen Bank, 28 miles off Gloucester; one from an equal distance out in the basin of the gulf (fig. 177); two from Nantucket; one from the Nova Scotian shore of the Bay of Fundy;[70] and one, put out close to the tip of Cape Cod (No. 22), went to Fire Island, New York.

These drifts, combined, show a definite surface set out of the southern side of the bay, dividing off Cape Cod, where some bottles took the southern route down past Nantucket, and so westward (which so many bottles from the Cape Cod line (line B) followed in July, 1922), while one, at least, was caught up in the southern side of the Gulf of Maine eddy, reproducing the drifts of bottles from the Cape Ann line of 1923 (p. 887).

The bottles set out in the eastern side of Cape Cod Bay followed a surprisingly definite set eastward and toward Provincetown, no less than 16 out of 21 stranding in that harbor or near by (all of them to the east and most of them well to the north of where they were set adrift) after intervals of 5 to 17 days (usually 5 or 6). Drifts of this sort suggest an anticlockwise movement of the surface water around Cape Cod Bay, with a subsidiary eddy of the same sort in Provincetown Harbor, which finally caught them up as they set northward along the inner shore of the cape.

Ten bottles set out in Ipswich Bay on April 7 (series J) give definite evidence of a southerly set around Cape Ann and into Massachusetts Bay, one of them having been found at Brant Rock, a few miles north of Plymouth, and two near Race Point, at the tip of Cape Cod, after intervals of 14 to 22 days. A fourth, picked up at Cutler, Me., at the western entrance to the Grand Manan Channel after 106 days, apparently had followed the southern side of the Gulf of Maine eddy, veering southeast, east, and northeast, and so paralleling the drift of bottles set out off Cape Ann in 1923 (line F; p. 887) and at about the same daily rate. A rather definite anticlockwise drift around the Massachusetts Bay region is thus indicated for winter and early spring by the combined drifts of the February and April series, its southern edge involving Cape Cod Bay but with the water farther north setting more to the eastward and so out past Cape Cod.

This same type of circulation is still more clearly reflected by the drifts of 40 bottles put out in Massachusetts Bay on the 20th to the 22d of that May (series K), drifts so easily interpreted as to demand rather detailed study. Eighteen of these were recovered—the largest percentage (45) for any series yet set out in the Gulf of Maine.

Following around the bay from north to south we find one or two bottles set out off Manchester[71] drifting to Marblehead and Nahant, while one bottle set

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[70] Freeport, Digby County.

[71] About 3 miles west of Gloucester.

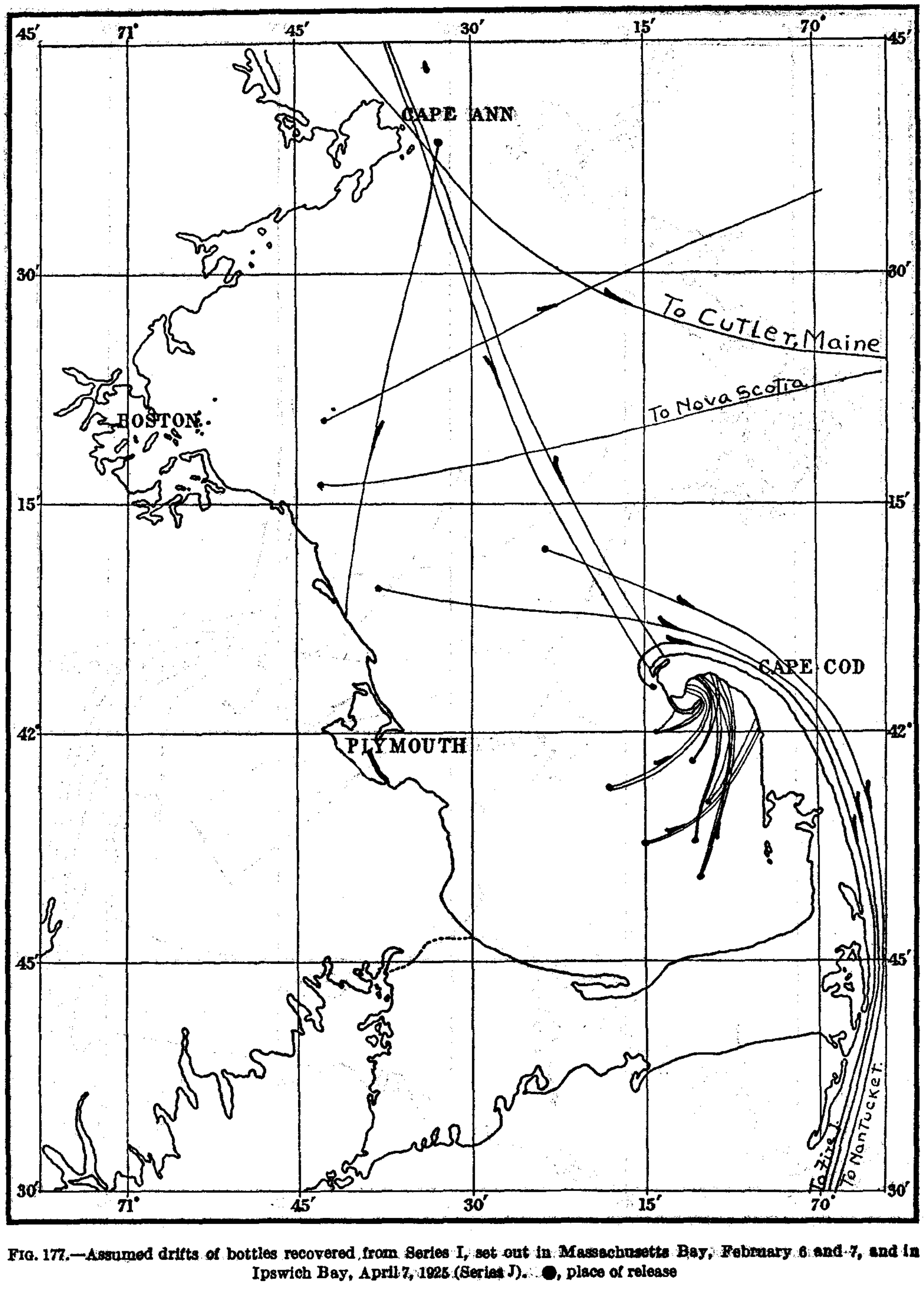

FIG. 177.—Assumed drifts of bottles recovered from Series I, set out in Massachusetts Bay, February 6 and 7, and in Ipswich Bay, April 7, 1925 (Series J). ●, place of release

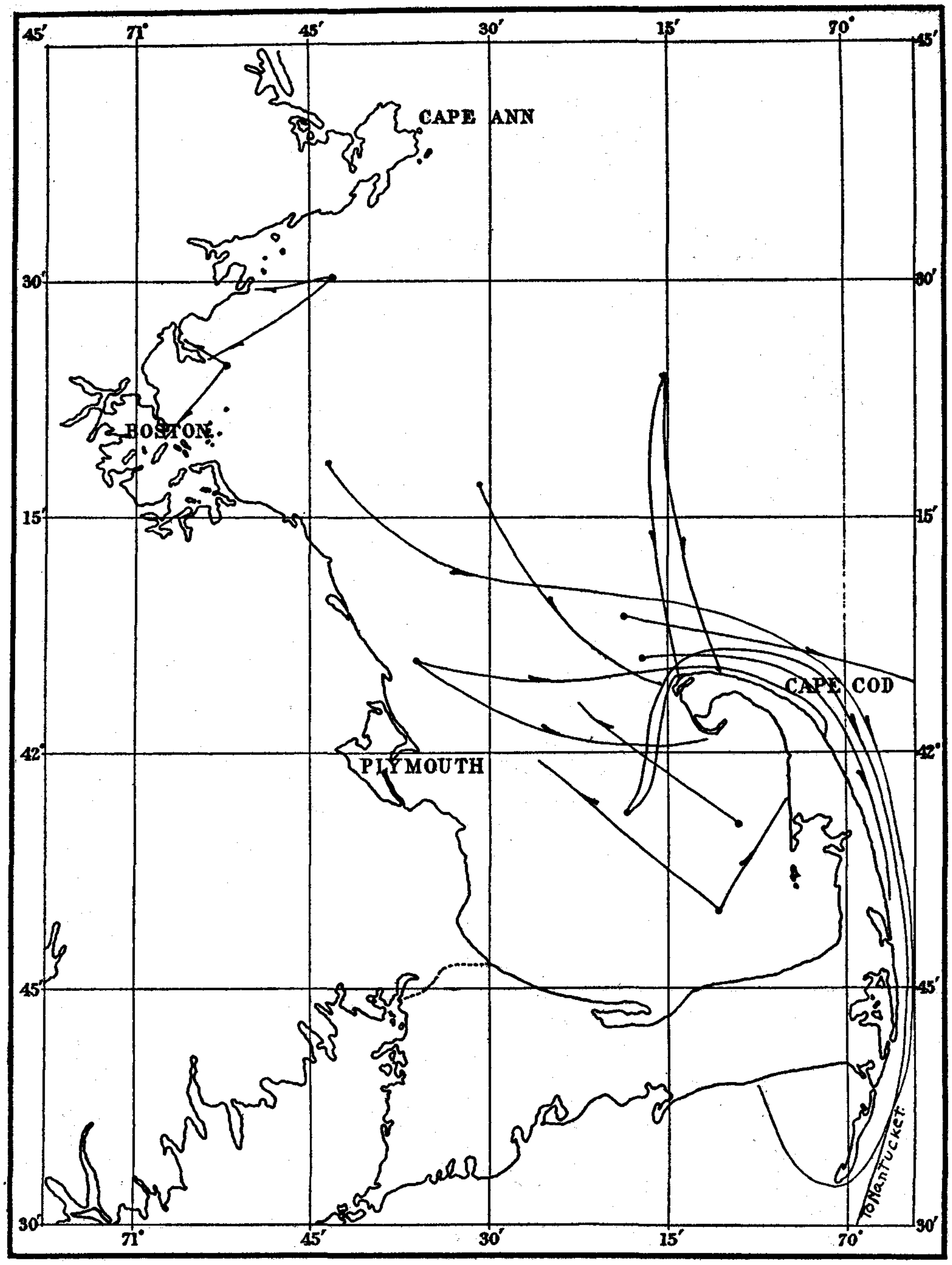

FIG. 178.—Assumed drifts of representative bottles recovered from series K, set out in Massachusetts Bay, May 20 to 22, 1925. ●, place of release

out near Nahant drifted west into Boston Harbor,[72] reflecting a definite set inward along the northern shore of the bay. On the other hand, bottles that were set out in the central part of the bay and at its mouth showed a tendency to drift southeastward, either to leave the bay or to be caught up at the tip of Cape Cod. Thus, one launched near Boston lightship reached Dennisport, on the south shore of Cape Cod (fig. 178); one set afloat on the southern side of Stellwagen Bank was picked up 75 miles east of Cape Cod Light 22 days later; while a third drifted from the offing of Race Point, at the tip of the cape, to Nauset Beach, some 16 or 17 miles down its outer shore. One of a pair set out in the western side of the bay a few miles north of Plymouth also rounded Cape Cod, but the other, also drifting eastward, stranded at Wood End, near Provincetown, while one from the center of the bay and two from its mouth, midway between the capes, were picked up on the beach at the tip of Cape Cod or floating near by.

The anticlockwise set, so clearly indicated by the drifts so far discussed from this series, was also shared by bottles set out in the eastern side of Cape Cod Bay; for all recoveries from this group were to the northward of where the bottles were set out. Two of them went out around the cape, one stranding at its tip but the other continuing southward past Cape Cod to Nantucket. One bottle set out off Wellfleet and another off Billingsgate Island would probably have followed a similar route if they had not been intercepted; for they went northwestward and were picked up midway between Plymouth and Provincetown after 9 and 11 days afloat. The companion bottle from the Billingsgate station (*Fish Hawk* station 7), however, was evidently caught in a different tidal current, for it went northeast to the Truro shore (fig. 178).

These Massachusetts Bay studies were continued by series L to N, set out in April, 1926, by Henry C. Stetson (p. 878). Twelve of the 41 bottles put out off Cape Ann (series L, fig. 179) have been recovered. One of these was from Race Point, at the tip of Cape Cod, in 32 days; four were from the outer shore of Cape Cod, south to Monomoy, in 30 to 66 days; two were from the south shore of Nantucket Island, near the western end, after 44 and 70 days. This general tendency southward across the mouth of Massachusetts Bay and so down past Cape Cod recalls the drifts of bottles from Ipswich Bay and out of Massachusetts Bay the spring before. The parallel between the two years is made complete by three returns from Nova Scotia at the mouth of the Bay of Fundy from the series of 1926 and one from the New Brunswick shore of the bay.

One of these Cape Ann bottles went to Point Clyde, at the western entrance to Penobscot Bay. Without the southern drifts just listed, for comparison, the tracks followed by these bottles to the Bay of Fundy would be conjectural. The former, however, make it as clear as evidence of this sort ever can that the general route was southward at first, with a division off Cape Cod, whence some continued southward but others were carried in an eddying course eastward and northward around the basin of the gulf. The Port Clyde recovery alone is puzzling, but the time interval (85 days) is sufficient to allow of a circuitous journey in its case also.

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[72] Another stranded close by.

The line (M) set out at the mouth of Cape Cod Bay from Manomet Point, Plymouth, to Provincetown, on April 21, 1926, showed an unmistakable movement of the water eastward, for 12 of the 28 were picked up near the tip of Cape Cod between Provincetown and Race Point, one passing out of the bay and thence southward to Nantucket. Two of the bottles set out off Truro (series N) also drifted to the tip of the cape at Wood End, the entrance to Provincetown Harbor.

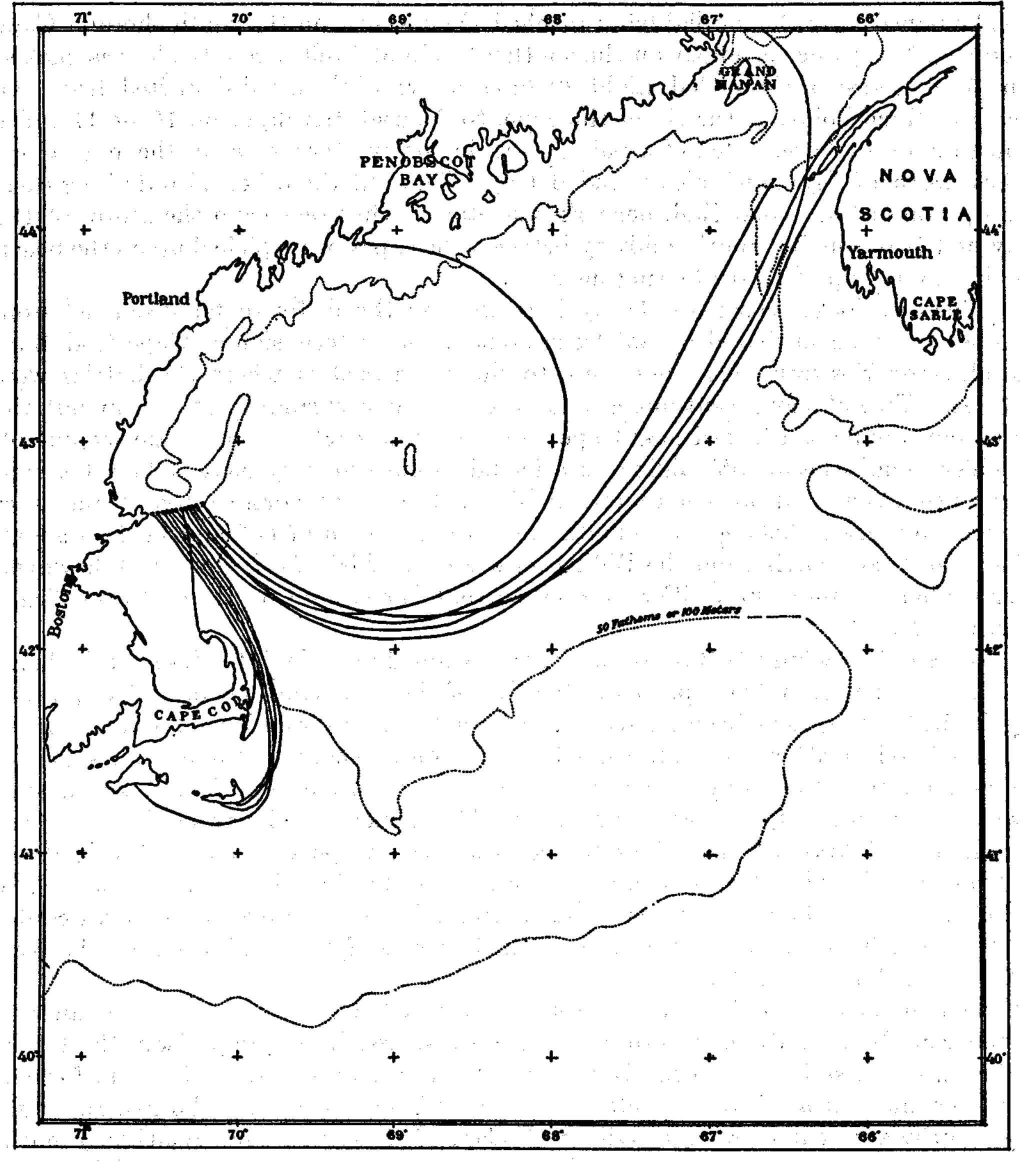

FIG. 179.—Assumed drifts of representative bottles recovered from Series L, set out off Cape Ann by H. C. Stetson, April 19, 1926. ●, place of release

In weighing the significance of drifts of this sort, when bottles are set out so close to land, due consideration must be given to the stage of the tide. In this instance all the bottles that showed a drift toward the north were set out on the flood tide, so that they must have traveled up the bay at first. Consequently, the fact that they stranded where they did indicates a predominance of ebb over flood, or in other words, a drift out of Cape Cod Bay along the eastern side.

Before leaving the bottle drifts in Massachusetts Bay, I should emphasize the fact that not one of them is clockwise, but that all can be safely interpreted anticlockwise within the bay or from north to south across its mouth and so down past Cape Cod.

At first sight the evidence (by bottle drifts) of a dominant set out of Cape Cod Bay around Cape Cod, and so southward along the outer shore of the latter, might seem contradicted by the physiography of the cape; for, as Davis (1896) has shown, the so-called "Province lands," which form its tip, were built up by the transference of sand along shore from the south. In fact, the existence of the sand spit known as Wood End, which incloses Provincetown Harbor on the southwest, is sufficient evidence of beach-drifting inward toward the bay, not outward from the latter, as the bottle drifts demand. However, this apparent contradiction vanishes on closer analysis. Beach-drifting[73] is effected chiefly by the longshore component of wave action.

A glance at the chart will make it clear that winds from the only direction (between north and southeast) that can drive a sea against the tip of the cape heavy enough to move much sand necessarily produce a wave current westward around its extremity. This would be the case even if the current a few hundred yards out (tidal or not tidal) were making in the opposite direction, perhaps carrying our drift bottles with it. Neither the tidal nor the nontidal currents scour the shore line here violently enough to be of more than minor importance.[74]

Thus, beach drifting may be constantly in one direction, but the dominant set of the water as constantly the opposite only a short distance out at sea; and it seems sufficiently established that this is the case at the tip of Cape Cod.

Farther south along the cape beach-drifting acts in the same direction as the nontidal drifts, both making to the southward.

The drifts from series O (set out near the coast, about midway between Cape Ann and Cape Elizabeth, on July 18, 1926, by T. E. Graves) proved consistent with these Massachusetts Bay drifts (as, also, with the drifts from the Bay of Fundy in 1919) for the three recoveries so far reported were all from the southward—two from Cape Ann and the other from the north shore of Massachusetts Bay at Salem.

DRIFTS OF BOTTLES SET OUT OFF CAPE ELIZABETH AND OFF MOUNT DESERT

The drifts so far discussed have proved so consistent, both regionally and from year to year, that the type of circulation which they represent may safely be taken as characteristic of the southern and southwestern parts of the gulf. The drifts of bottles put out off Cape Elizabeth and Mount Desert have proven equally consistent among themselves, though interpretation has not been so easy.

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[73] Johnson (1919 and 1925) has proposed this convenient term for the longshore transference of sand or other débris.

[74] For an illuminating discussion of the relative importance of wave and other currents in causing beach-drifting, see Johnson (1919; 1925, p. 505).

We may first consider the outer half of the Cape Elizabeth line of 1922 (line **A**, p. 871, fig. 180) as the easiest to understand. Sixteen of these 150 bottles were recovered, as follows: Outer coast of Nova Scotia (Scotts Bay), 1; vicinity of Cape Sable, 1; mouth of Penobscot Bay, 2; western shore of Nova Scotia and southern shore of the Bay of Fundy, 12. Thus, the net drift for the great majority of these bottles was toward the east and northeast. The fact that so many of them stranded along the same sector of the Nova Scotian coast where bottles from the Cape Ann and Cape Cod lines have been picked up (figs. 174 and 176) makes it likely that they, too, veered from southeast to east in their journey across the gulf, to continue northeastward along the Nova Scotian coast in the drift shown there by current measurements (p. 861). The rapid drift of one bottle from the outer part of this line (No. 280) to the Salvages Ledges (about 25 miles east of Cape Sable), where it was picked up 67 days after release, points similarly to a rather direct track toward the east at first; for it can not have followed a very circuitous route unless it drifted faster than is at all likely. It is on these bases that the probable drifts are laid down on Figure 180.

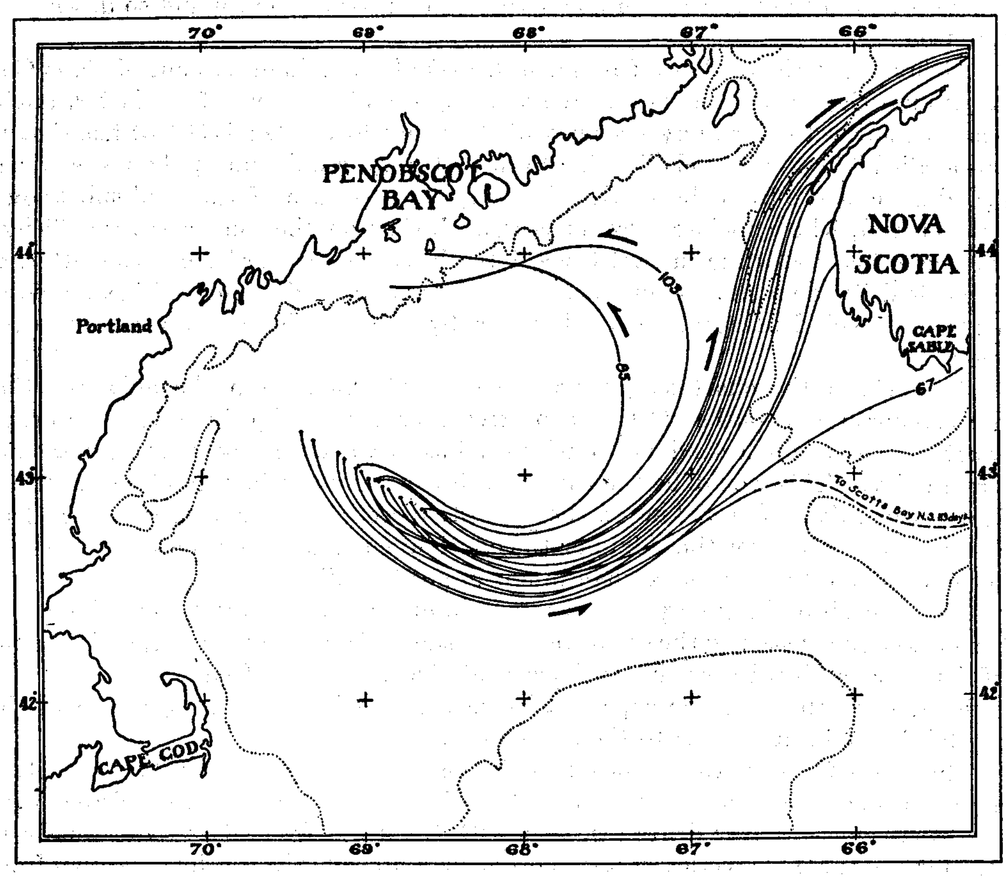

FIG. 180.—Assumed drifts of bottles recovered from the outer half of series A, set out off Cape Elizabeth, July 1, 1922. ●, place of release

Why the bottle last mentioned (No. 280) escaped the drift setting northward toward the Bay of Fundy is not clear. However, that it did escape, to continue eastward, proves that the surface current that sometimes flows westward past cape Sable was not active at the time. On the other hand, the fact that only two bottles of all this group were found on the outer Nova Scotian coast east of the cape, while so many turned toward the Bay of Fundy, is conclusive evidence that there was no general flow past the latter, but that its offing was comparatively a dead water at the time so far as any nontidal current is concerned.

It is not possible to reconstruct the track of the "Salvages" bottle in its rounding of the cape; it may have held farther offshore than its line, as laid down on the chart, would suggest, and then have veered inshore again. Bottle No. 165, which drifted from a point a few miles inshore of Cashes Ledge to Scotts Bay, 50-odd miles beyond Cape Sable, may have been caught up in the Nova Scotian eddy, judging from the considerable interval between release and recovery (113 days).

More interesting, in connection with the general circulation of the Gulf of Maine, are the two bottles (Nos. 210 and 284) that went from the outer section of line A to the mouth of Penobscot Bay. The direct route for these would be to the north, of course, but it is most unlikely that they followed such a course at right angles to the general easterly drift followed by the other bottles that went to Nova Scotia from this same section of the line. The fact that they were afloat about as long (85 and 103 days) as several of the bottles that reached the Bay of Fundy[75] also makes it likely that all the bottles of this group drifted southeastward and eastward at first. On this basis the most reasonable explanation for the eventual separation is that while most of the bottles approached the Bay of Fundy close enough to the Nova Scotian shore to be swept inward, reproducing the drifts of Mavor's bottles in 1919 (p. 868), others, circling on a shorter radius, hence following a more northerly route, crossed the mouth of the Bay of Fundy instead of entering it, were picked up in the current that flows out of the bay past Grand Manan, and so were carried westward again. This is made the more likely by the fact that several drift bottles put out in the Bay of Fundy in 1919 traveled by this same route to points along the Maine coast, one of them to the same destination (Penobscot Bay; p. 870). It is probable, therefore, that the two bottles that went from the vicinity of Cashes Ledge to Penobscot Bay in 1922 made a partial, anticlockwise circuit, which brought them well over toward the eastern side of the gulf en route, so that they approached their eventual destination from the east or southeast, not directly from the south.

The route of the Matinicus bottle is carried the farther eastward of the two on the chart (fig. 180), because of its longer interval; but there is no means of knowing whether this apparent difference is actually significant.

On the whole, the most instructive feature of this group is the uniformity of the drifts and the very definite and comparatively rapid movement of the water which these show along a narrow track from the center of the gulf to the Nova Scotian side of the mouth of the Bay of Fundy.

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[75] No. 190 to Grand Passage, 116 days; No. 206 to Digby Neck, 90 days; No. 241 to Port Lorne, 88 days; No. 242 to the offing of Digby, 70 days; Nos. 248 and 255 to the vicinity of Point Prim, 75 and 90 days; No. 264 to Long Island, at the mouth of the Bay of Fundy, 81 days; No. 299 to Advocate Harbor, Nova Scotian shore of the Bay of Fundy, 107 days.

The inshore half of the Cape Elizabeth line of 1922 (line A, fig. 181) is more puzzling. These recoveries fall into four groups, so distinct and so far separated that the bottles must have scattered widely within a short time after they were put out. Four bottles from the outer half of the section went to the Bay of Fundy; three others were picked up along the coast of Maine between Jonesport and the western entrance to Penobscot Bay, the same sector to which several bottles drifted from the Bay of Fundy in 1919; one went southward to the Isles of Shoals, off Portsmouth; and six were found in Casco Bay or along the coast a few miles to the eastward of it. The recoveries from the inner end of the line were all from near-by localities, either in the Casco Bay region or along the southern shore of Cape Elizabeth.

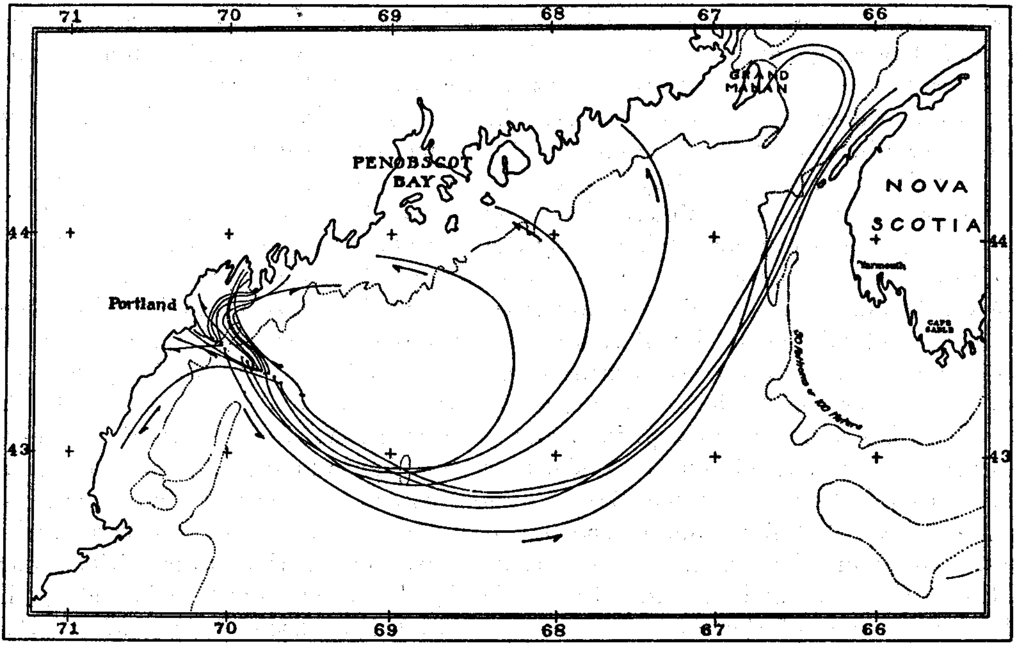

FIG. 181.—Assumed drifts of bottles recovered from the inshore half of Series A, set out off Cape Elizabeth, June 30, 1922 ●, place of release

If the two halves of line A be compared (figs. 180 and 181), it is at once evident that the percentage of bottles that went to Nova Scotia was much greater (14 bottles) for the outer than for the inner half, and that all the bottles that traveled this route were set out more than 10 miles from the land. If the drifts from the inner end of line A had been the only evidence available, the natural conclusion would have been that their general set was eastward along the coast of Maine. The evidence of the other series discussed so far forbids this, however. In the first place, the Bay of Fundy series of 1919 drifted in the opposite direction (p. 870), as several bottles set off Mount Desert in 1923 did, also (p. 902). Furthermore, all the bottles from the Cape Cod, Cape Ann, and Cape Elizabeth lines that were recovered in the Bay of Fundy region were reported from so short a sector of the coast that they must have followed a very uniform track, which for the Cape Ann and Cape Cod lines veered unmistakably through southeast, east, and northeast (p. 889). The time intervals are consistent with this, also, the great majority ranging between 70 and 105 days, irrespective of which line the bottle in question was launched from. For any of the bottles from the Cape Elizabeth line to have reached the southern shore of the Bay of Fundy by the alternative route via the coast of Maine and through the Grand Manan Channel would have involved a drift from north to south across the Bay of Fundy directly contrary to the dominant set established there by Mavor's (1922) experiments with drift bottles, as well as by measurements of currents (p. 861). Such an explanation would also be contrary to the time intervals, for the two bottles that went from the offing of Cape Elizabeth to Grand Manan and to The Wolves (Nos. 43 and 88) and were not reported until 103 and 104 days after release, while two others, set afloat near by (Nos. 99 and 105), were reported from the Nova Scotian side of the Bay of Fundy in 80 to 98 days.

By this reasoning the bottles that went to Penobscot Bay from the inner end of line A, and to the coast of Maine farther to the eastward, may safely be credited with essentially the same route as those that reached this same sector of the coast from the outer end of this line, circling anticlockwise at first toward the Bay of Fundy, to return westward again. The time intervals between release and recovery (80 days for No. 65, picked up at Jonesport; 63 days for No. 98, reported near Swans Island; and 103 days for No. 87, found at Matinicus) favor this interpretation.

The general uniformity, both of localities of recovery and of time intervals, for the outer two-thirds of line A, indicates a well-developed, dominant set of the anticlockwise sort just outlined. This, however, seems hardly to have affected the surface water within 15 miles of the land at the time, judging from the regional dispersion of the returns from the inner end of line A and from the fact that the time intervals between release and recovery vary widely for these, quite independent of the distances which this group of bottles made good. Thus we find intervals ranging from 25 to 77 days for 7 bottles that were picked up in the Casco Bay region, 15 to 30 miles from the points of launching, and 5 to 72 days for 5 bottles recovered along the southern side of Cape Elizabeth after journeys of 8 to 23 miles. One was found at Monhegan Island (35 miles) in 47 days, but another, reported from Daniscove (25 miles), was not found until 75 days had passed.

Of course, little stress can be laid on the time interval for any one bottle, because there is no knowing how long it may have lain on the shore, overlooked; but our general experience suggests that if bottles are not reported comparatively soon after stranding they are either broken or buried in windrows of seaweed and never after heard from at all. Consequently, when time intervals vary widely for bottles drifting only a short distance to a coast as frequented as the Casco Bay region is, contrasting with uniformity of intervals for bottles journeying right across the gulf, it is obvious that the former did not follow as definite a set as the latter. On the whole, the regional distribution of the localities of recovery for the inner end of this Cape Elizabeth line trends eastward across Casco Bay, pointing to an irregular eddying drift in that direction as involving the mouth of the latter. Cape Elizabeth, however, seems to have bounded this eddy on the south at the time, witness the several strandings to the south of the cape (fig. 181); the fact that one bottle, set out about midway of line A was recovered at the Isles of Shoals after 100 days points to some movement of surface water southward along the coast sector between Cape Elizabeth and Cape Ann.

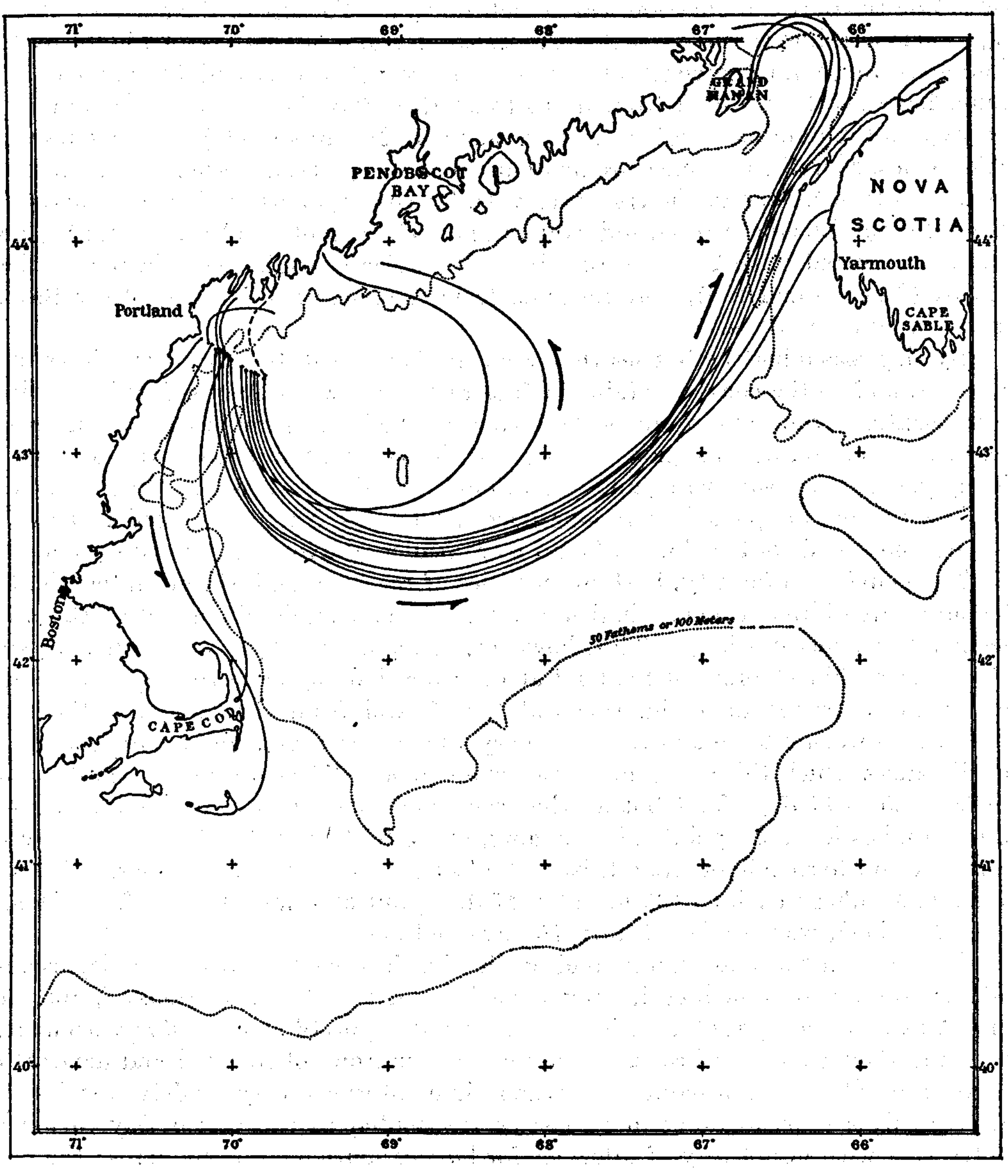

FIG. 182.—Assumed drifts of representative bottles recovered from Series E, set out off Cape Elizabeth, August 7, 1923. ●, place of release

The drift of a second line of bottles set adrift off Cape Elizabeth a year later (in August, 1923; series E, p. 874) showed much the same grouping as that just described for the corresponding line of 1922 (series A). Two recovered from the outer part of the line were from the west coast of Nova Scotia (fig. 182); three were from the entrance to the Bay of Fundy, on the Nova Scotian side; two were from the New Brunswick side of the Bay of Fundy; and three were from the southern side of Grand Manan; totaling 9 per cent of the number set out. These drifts so closely reproduce (in their regional distribution) the recoveries of bottles set afloat farther out along this same line the year before (line A; fig. 181) and off Cape Ann in 1923 (fig. 176) that most of them, no doubt, followed a uniform route, at least in their journey northward toward the mouth of the Bay of Fundy.

It is evident that most of the bottles from line E moved offshore from the time of their release, otherwise more strandings would have been reported from the coast line to the southward. However, the fact that one of them was recovered at Nantucket, a second on the outer shore of Cape Cod, and a third at Beachwood, Me. (Nos. 1702, 1712, and 1731; intervals, respectively, of 138, 121, and 34 days), makes it probable that they followed a southeasterly course at first. Negative evidence to the same effect results from the fact that only two bottles from this line were found anywhere along the coast of Maine between Seguin Island and the Bay of Fundy, contrasting with the considerable number of recoveries from Nova Scotia. Had the set been eastward along the coast of Maine, such as would be represented by a straight line between the points of release and recovery, a considerable number of recoveries might have been expected along that 140-mile sector, where the tide draws strongly into the numerous bays, bringing in large amounts of drift of all kinds. It is fair to assume, also, that the route across the gulf was about as long for series E as for the Cape Ann series, because three of the latter were reported from Nova Scotia after intervals as brief as any from the northern lines; one, namely from Yarmouth, in 60 days; another from Port Maitland in 64 days; and one from Cockerwit Passage in 65 days (p. 875). However, it seems that the Cape Elizabeth groups swung east before reaching the Cape Ann line, because so many more of the former reached Nova Scotia than of the latter; i. e., that on the whole the two groups of bottles followed different routes until they converged toward the eastern side of the gulf.

The repetition, from year to year, of drifts most easily reconcilable with an anticlockwise eddying set argues strongly in favor of the prevalence of this type of circulation around the southern side of the basin of the gulf. Only one drift (No. 1773) from the two series so far launched off Cape Elizabeth (series A and E) has been hard to reconcile with this; because, if the date of recovery is correctly stated, its time interval from the offing of Cape Elizabeth to Grand Manan (56 days) is smaller than for any other bottle that crossed from the western side of the gulf to the Bay of Fundy. Granting it a direct journey, this means a daily rate of 2.7 miles, or at east 4.7 miles if it followed the eddying route, which is more likely.

The time intervals between the dates of release and recovery for bottles drifting from the offing of Cape Elizabeth to Nova Scotia averaged considerably shorter in 1923 (56 to 111 days; average 75 days for line E) than in 1922 (75 to 146 days; average 103 days for line A). Taken at its face value, this difference would point either to a more rapid rate of travel or to a more direct route, which in this case would mean veering more directly eastward. It seems more likely, however, that the difference is not as significant as it might appear, but that the discovery of the bottles and the local interest aroused thereby stimulated a closer scanning of the Nova Scotian shores in 1923, so that the bottles were found soon after they stranded, instead of lying on the beach perhaps for a week or more. The fact that one bottle, which drifted right up the Bay of Fundy to Advocate Harbor at Cobequid Point, at its head, was picked up in 107 days affords direct evidence to this effect, the distance on the assumed track being more than 250 miles.

With this uncertainty introducing a source of error that may be very considerable, I have not thought it justifiable to assume a shorter route for the bottles drifting to the mouth of the Bay of Fundy in 1923. The probable routes within the Bay of Fundy of such bottles from line E as entered the latter are laid down on the chart (fig. 182) to accord with the drift bottles set out there by Mavor in 1927 (i. e., crossing it from south to north and then continuing to veer westward to Grand Manan), because this type of circulation seems sufficiently established there.

Line E reproduces the corresponding series of the preceding year (line A), not only in the preponderance of drifts to Nova Scotia and in the uniformity of the tracks probably followed, but also in the recovery of one bottle at Metinic Island, off the western entrance to Penobscot Bay (No 1792), and of another at Round Pond Harbor, a few miles farther to the west (No. 1740). The time intervals for these (respectively, 64 and 77 days) correspond as closely as could be expected with 63 and 103 days for the two bottles (Nos. 98 and 284) that drifted to this same sector the year before (figs. 180 and 181), and hence suggest the equally circuitous offshore route laid down on the chart. However, it is possible that the two bottles in question (Nos. 1740 and 1792) actually circled in the opposite direction (i. e., clockwise), drifting inshore at first in company with four others that were picked up in Casco Bay and a few miles to the east of it, then continuing eastward along the coast, perhaps through the channels between the islands. The fact that one bottle (No. 1793) from the outer end of line E was found in Sheepscott River[76] after 34 days lends likelihood to this possibility.

The Cape Elizabeth series for the two years, however, illustrate an anual difference of another sort; namely, that the coastal belt, 10 to 15 miles broad next the cape, was a sort of deadwater in 1922 (p. 899), while in 1923 the general dominant set governed closer in to the coast.

BOTTLES SET OUT OFF MOUNT DESERT, AUGUST, 1923

The drifts of the bottles of the Mount Desert line can be approximated only if they are taken in conjunction with the several series discussed so far. Standing by themselves they would be self-contradictory, for 8 were recovered at significant distances to the westward (figs. 183 and 184); 11 were recovered at significant distances to the eastward; and 6 others at points close to where they were released. The easterly drifts so far reported all lead to the coast of Nova Scotia, except for one to the coast of Maine at the western entrance to the Grand Manan Channel (No. 1584, Haycock Harbor, Washington County). By themselves, these would naturally suggest a set to the northeast from the offing of Mount Desert, but analysis makes this most unlikely.

The fact that these Nova Scotian recoveries are distributed along the same sector of the coast line where bottles from the Cape Elizabeth, Cape Ann, and Cape

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[76] Stated in the returns as "Sheepshead" River.

Cod lines have stranded would of itself be strong evidence that the routes of all had converged into one general and rather definite track some distance before they reached the land. In this respect the correspondence between the Mount Desert line of 1923 and the outer half of the Cape Elizabeth line of 1922 (series A, fig. 180) is as close as could have been expected had all these bottles been launched on the same line and on the same day. In fact, this correspondence extends even to the odd bottles that diverged from the majority grouping, one or two having reached

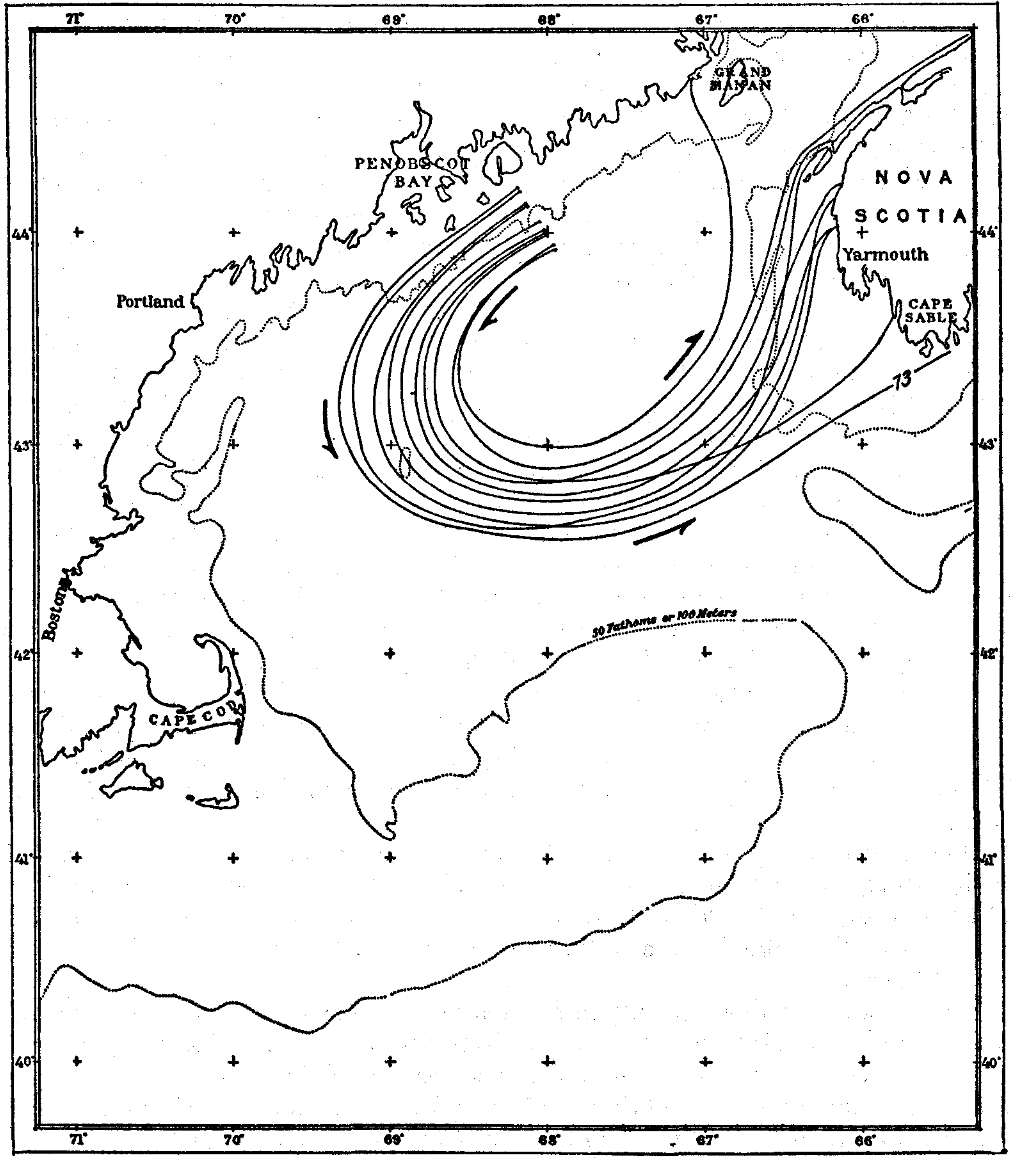

FIG. 183.—Assumed drifts of representative bottles recovered to the eastward from Series D, set out off Mount Desert Island, August 6, 1923. ●, places of release

the vicinity of Cape Sable, and one or two found along the coast of Maine well to the eastward, in each instance. In the case of the drifts that cross the gulf, this track, I believe, is now definitely proven to approach the Bay of Fundy from the south or southwest, by the evidence just detailed.

The relationship which distance traveled bears to time interval between release and recovery also argues for a circuitous route for the bottles that went to Nova Scotia from the Mount Desert line, because the average distance for all of them, in a direct line, would be only about 85 miles, though the times range from 62 to 88 days for 8 of 10[77] (averaging 70 days). Evidence of this sort must, of course, be used with discrimination, because there is no knowing how long a bottle lies on the beach before it is noticed. When the results prove reasonably consistent, however, some trust can be put in them. In the present connection we have as a standard for comparison the Nova Scotian drifts from the lines set out off Cape Elizabeth. The distance (in a direct line) is only about one-half as great from Mount Desert to Nova Scotia as from Cape Elizabeth. The two lines of 1923 were set out only one day apart, and there is no reason to suppose that bottles from one line would be consistently overlooked while bottles from the other would be soon found. Consequently, it is reasonable to assume that some of the Mount Desert bottles would have been found a month or more before the first were reported from the Cape Elizabeth line, unless they had journeyed by a very circuitous route. Actually, however, the first four recoveries for the former were on October 7 to 9; the first three of the latter on the 9th and 10th. Allowing the one day's difference in the dates when the two series were put out, we have the rather surprising fact that the time intervals for these two groups, launched almost 100 miles apart, were the same almost to a day, though the strandings were scattered along more than 20 miles of coast line between Yarmouth, Nova Scotia, and the mouth of the Bay of Fundy.

The time intervals for the Nova Scotian drifts as a whole, from these two series, also correspond much more closely than the difference in direct distance would have suggested as probable, averaging about 75 days for the Cape Elizabeth series (extremes of 56 to 111 days; p. 875) and about 70 days for the Mount Desert group (62 to 151; p. 874).

The percentage of recoveries is not only of the same general order of magnitude for the Mount Desert line as for the Cape Elizabeth line of 1923 (respectively, 28 and 19 per cent), but the Nova Scotian and Fundian returns formed almost the same proportion of the total for the former (36 per cent of the total returns) as for the latter (42 per cent).

The most reasonable explanation for this correspondence between the two series, and the only explanation that fits all the facts just outlined, is that the journey to Nova Scotia covered about as long a distance for the Mount Desert bottles as for the Cape Elizabeth bottles, and that the former drifted southwestward at first, to join the general route of the latter group from west to east across the gulf.

Bottle No. 1584, set adrift about 25 miles out from Mount Desert Island and picked up at Haycocks Harbor, on the north shore of the Grand Manan Channel, 93 days later, probably followed the same general track as the bottles that went to

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[77] Three others (Nos. 1530, 1551, and 1557), which were not picked up until 133 and 151 days had passed, may have lain unnoticed on the beach or drifted in and out along the shore with the tides.

Nova Scotia. It may have entered the south side of the Bay of Fundy, come out again past Grand Manan, and then circled the western end of the latter and so into the channel, as would be compatible with the current measurements in that region. Or it may have circled northward past the mouth of the bay but close enough to Grand Manan to be caught up in the indraft into the channel.

The general conclusion that all this group of bottles followed an eddylike course and did not drift directly eastward is directly corroborated by nine bottles from this same line, picked up to the westward along the coast of Maine. The fact that these were set out at intervals from the inner end of the line to the outer is evidence that the surface was involved in this movement for at least 25 miles out from the land.

Two bottles from the inner end of the line, picked up on Great Duck Island two days later, may have made their journey on the tide, for they were set out early in the ebb,[78] which sets toward the southwest here. A greater distance covered (10 miles) makes it likely that bottle No. 1515, which went to Long Island (also to the westward), made its landfall on the second tidal period; and it is certain that No. 1521, which went from the inner end of the line to Kennebunk, Me. (a distance of about 107 miles in a direct line), in 32 days, was carried with a very definite drift, for its rate was not less than 3½ miles per day. The daily rate of another bottle (No. 1523), which went from the mid section of the line to a point 8 miles southeast of Isle au Haut, 31 miles away, was ostensibly much more rapid, for it was reported as picked up the day after it was set out. This date, however, can hardly have been correct Allowing one day's error (which is probably the correct explanation), the daily rate would be about 7 miles to the westward.[79]

The rapidity of these westerly drifts, which can not be disputed, makes it likely that four other bottles that went from this line to the entrance to Penobscot Bay and to St. Georges River, a few miles farther west (Nos. 1553, 1565, 1566, and 1599), but were not found until after 35 to 38 days afloat, were drifting to and fro with the strong tides of Penobscot Bay for some days before they stranded and were noticed.

It is impossible, of course, to determine how far any given bottle, which moved westward from the Mount Desert line but did not soon strand, may have paralleled the coast before veering offshore toward the center of the gulf, but it is probable that most of them did so somewhere between the longitudes of Penobscot Bay and Cape Elizabeth. Had their general route led farther westward, more bottles from the Cape Elizabeth line might have been expected to show a southerly drift than the few actually so reported (p. 901).

Some few bottles from the Mount Desert line, hugging the shore line closest, may have crossed the Cape Elizabeth line, but the time intervals between release and recovery make it more likely that all that went across the gulf from the offing of Mount Desert passed to the seaward of the outer end of the Cape Elizabeth line—i. e., more than 25 miles offshore—and it is so indicated on the chart (fig. 182).

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[78] It was high tide at Southwest Harbor at 6.26 a.m. on that day; the bottles in question (Nos. 1503 and 1510) were put out shortly afterwards.

[79] Assuming that it was picked up in the afternoon.

The tracks of three bottles from the mid section of line D, which were picked up at the eastern entrance to Frenchmans Bay, and one other that went to the vicinity of Petit Manan, are more puzzling. Ostensibly these point to short easterly drifts of 8 to 12 miles, and the time intervals are so uniform (33 to 38 days)[80] that all of them seem to have followed approximately the same route, though set out some miles apart. However, the time between release and recovery is so long for direct journeys so short, when contrasted with the rapidity with which other bottles set out near them drifted in the opposite direction, that it seems virtually certain that they followed a roundabout route. Judging from the facts that many more bottles stranded to the westward and that all of this series (D) were set out on the ebb, it is probable that the four bottles in question also drifted westward at first. Their most likely route would then be into Blue Hill Bay with the next flood, around Mount Desert Island, and so out again through Frenchmans Bay, to strand about Schoodic Promontory and to the eastward of it. Such a drift would be consistent with the clockwise circulation to be expected around Mount Desert Island, on theoretic grounds (p. 970). In short, the bottles set out off Mount Desert in 1923 afford definite proof of a set westward along the coast of Maine but no clear evidence of any longshore set in the opposite direction.

On the basis of the foregoing analysis, the most reasonable explanation of the localities where bottles from the Mount Desert, Cape Elizabeth, Cape Ann, and Cape Cod series of 1923 were recovered, and of the periods of time between the dates they were set afloat and later were picked up, is that bottles from all three lines moved in tracks eddying counterclockwise through southwest, through east, to north, and veering on successively shorter and shorter radii of curvature. Thus, the few bottles from the two southernmost lines, which were found on the Nova Scotian coast, probably traveled easterly from the time they were set out (southeast at first, then east and northeast), but the farther north and east along the coast bottles were put out, the more they tended to circle to the right of a direct course. It is also likely that while the breadth of the track covered by all the bottles in the western side of the gulf was something like 100 miles, they tended to converge into a narrower track as they approached the eastern side of the gulf.

In August, September, and October of 1922 and 1923 the center of this eddylike circulation seems to have been situated 40 to 60 miles south of Mount Desert Island, over the northeastern extension of the deep trough of the gulf.

The fact that the great majority of the recoveries from Nova Scotia and from the Bay of Fundy were from a rather short stretch of coast leads to the conclusion that no matter on which line the bottles in question were released, all those that drifted across the gulf finally came within the influence of the same south-north current, hugging close to the eastern shore. On no other assumption, I believe, is it possible to reconcile the facts just stated with the time element (p. 904) and with the current measurements that have been taken in that side of the gulf (p. 861).

The recoveries on the coast of Maine already discussed point to a division of this northerly set before it reaches the Bay of Fundy, the greater volume entering the bay along its southern shore, but offshoots (which may be only intermittent)

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[80] No. 1511 was picked up in Winter Harbor 11 months later, a period so long that there is no way of estimating how far it may have traveled en route, or how long it may have lain on the strand.

from its western side recurving to the left across the mouth of the bay. Flotsam drifting in this branch may then come under the influence of the drift setting eastward into the right-hand side of the Grand Manan Channel. But only one bottle can so be classified, while five seem to have passed by the channel in their rounds to Penobscot Bay.

It is interesting that only two bottles from any of the several series[81] have been recovered along the coast sector between Petit Manan and the western entrance to the Grand Manan Channel, although many must have passed by. Judging from this, such parts of the dominant surface drift as veers westward past Grand Manan does not usually strike the coast of Maine in summer until it has passed the longitude of Mount Desert Island.

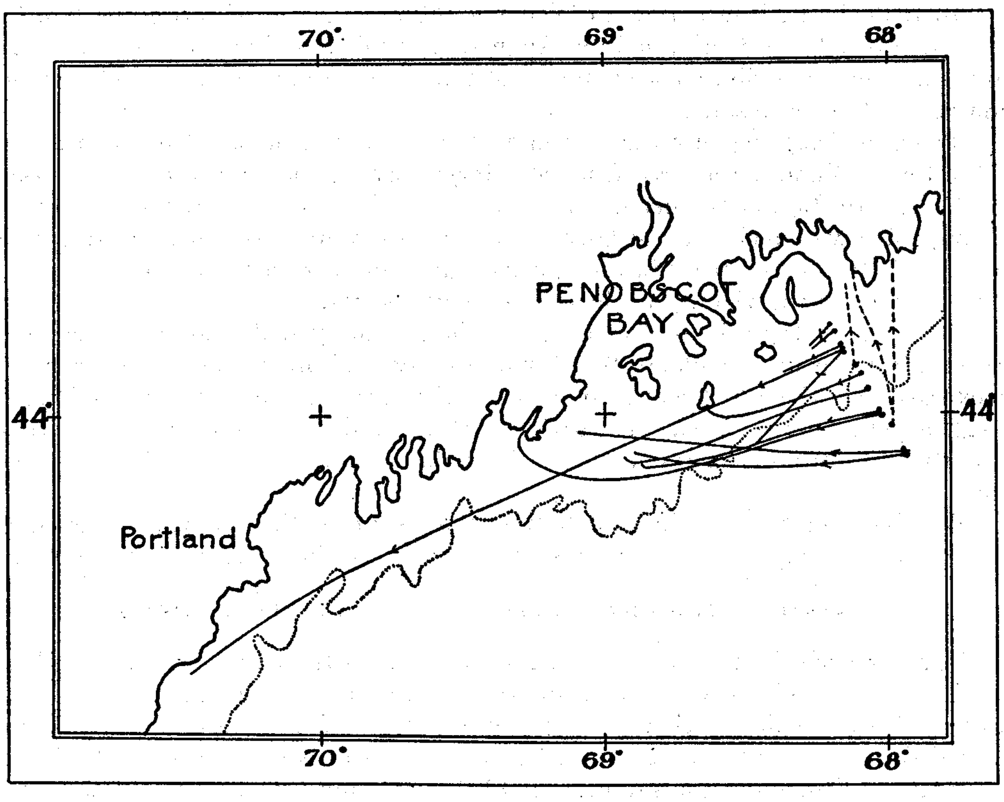

FIG. 184.—Assumed drifts of bottles recovered to the westward and inshore from Series D, set out off Mount Desert Island, August 6, 1923. ●, places of release

The circulatory scheme just outlined reconciles the bottle drifts for 1923 with those of the bottles set out in the Bay of Fundy in the summer of 1919, except that the latter certainly hugged the coast more closely in their westward and southward journey, else so many of them would hardly have been embayed behind Cape Cod. In this respect the summer of 1919 paralleled the April and July currents of 1925

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[81] One set out in the Bay of Fundy in August, 1919 (Mavor, 1922, bottle no. 181); the other (no. 65) from the inner part of the Cape Elizabeth line of July, 1922.

and 1926, which carried bottles past Cape Ann, from Ipswich Bay into Massachusetts Bay (pp. 890, 893).

In the summers of 1922 and 1923 so many more bottles were picked up along Nova Scotia than in the western side of the gulf (a difference hardly accidental, because the coast line between Cape Elizabeth and Cape Cod is much frequented) that the surface water was evidently moving more offshore in the western side of the gulf, inshore in the eastern, than was the case in 1919.

BOTTLES PUT OUT OFF WESTERN NOVA SCOTIA

In 1926 the Biological Board of Canada put out four sets of bottles (each of 120) off Yarmouth, Nova Scotia, in July, August, September, and October, and Dr. A. G. Huntsman has contributed a summary of the recoveries in advance of his publication of the detailed results.

The great majority of returns from all the sets were from the Nova Scotian side of the Bay of Fundy, scattered from St. Marys Bay, at the mouth, to Minas Basin and Chignecto Bay, at the head. Six others crossed to the New Brunswick shore of the bay; five were picked up at Grand Manan; two went to the coast of Maine, one to Cape Cod; and two went in the opposite direction, eastward, past Cape Sable to Cape Negro and the vicinity of Shelburne, Nova Scotia.

As a whole, these drifts demonstrate the northerly drift along western Nova Scotia into the southern side of the Bay of Fundy, and up it. The New Brunswick recoveries show the anticlockwise movement within the bay, brought out by Mavor's (1923) experiments (p. 868). The drifts to Maine and Cape Cod are in line with the westerly and southerly drifts of bottles from the Mount Desert and Cape Elizabeth lines.

By what counterdrift the two bottles that went to the eastward escaped the Gulf of Maine eddy and came within the influence of the Scotian eddy is not clear.

DRIFTS OF BOTTLES ENTERING THE GULF FROM THE EASTWARD

The northerly drift along the Nova Scotian side of the gulf to the Bay of Fundy and its anticlockwise eddying continuation along the coast of Maine are further illustrated by the destinations reached by a considerable number of bottles that entered the gulf from lines set out off the outer coast of Nova Scotia by the Biological Board of Canada in the summers of 1922, 1923, and 1924. The following data have generously been contributed by Doctor Huntsman in advance of publication.

Two bottles from a line set out southeast across the continental shelf from Brazil Rock on July 17, 1922, were picked up along the western coast of Nova Scotia; 8 in the Bay of Fundy; and 2 circled farther westward, 1 of them to Winter Harbor and the other continuing past Mount Desert to the neighboring Long Island. The localities of release were scattered from 2 to 59 miles out from Brazil Rock, and none of the bottles set adrift farther out were reported from the gulf.

The bottle that went to Long Island made so rapid a drift (45 days from release to recovery) that no doubt it passed across the mouth of the Bay of Fundy. The Winter Harbor bottle, with 77 days, may have entered and circled the bay.

The next summer a series roughly at right angles to this last was set out on a line running northeastward from the western end of Browns Bank. Fourteen of these were reported from the Gulf of Maine; 6 of them scattered along the west shore of Nova Scotia; 7 were from widely separate localities in the Bay of Fundy, from its mouth to its head, after intervals of 64 days and upward; and 1 was from Penobscot Bay, Me. The drifts are thus much the same as those of the preceding summer, hugging the Nova Scotian coast to the Bay of Fundy. The time interval for the Penobscot Bay bottle was so long (113 days) that it, too, may have entered and circled the bay.

Twelve bottles from lines set out off Country Harbor, off Beaver Island, and off Cape Canso, Nova Scotia, were also reported from the Gulf of Maine (all of them from Yarmouth and northward along the western coast of Nova Scotia) and from the two sides of the Bay of Fundy. Only a single bottle from these eastern lines has yet been reported from the western side of the gulf—one set adrift a few miles off Sable Island by the Ice Patrol cutter *Tampa* on April 18, 1924, and picked up at Gloucester, Mass., 118 days later. The distance in a direct line being about 450 miles and something like 500 miles by the probable route around the northern side of the gulf, this bottle made an unusually rapid journey.

Since the preceding was written, Doctor Huntsman has contributed a summary of five monthly series, each of 200 bottles, set out offshore from Brazil Rock (off Cape Sable), July to October, 1926. Twenty-six of the 35 returns from the July set were close by, five from the Nova Scotian shore of the Bay of Fundy, and two from the New Brunswick side. The 46 returns from the August series were similar, except that the proportion of near-by returns was smaller (16); of returns from St. Marys Bay and the Nova Scotian shore of the Bay of Fundy larger (29). Fifteen of 23 returns from the lines of September 1 were again from this same sector of the Bay of Fundy region, three from the New Brunswick shore, and five between the point of release and Cape Sable. Three of the 15 returns from the series of September 27, however, were from the eastward (Shelburne to Port Mouton), nine near where set out, and only three from the Bay of Fundy. The series of October 20, again, gave 50 per cent of returns (six) near-by, four returns to the eastward (Negro Harbor to vicinity of La Have River), with two, only, from the western coast of Nova Scotia within the Gulf of Maine.

In sum, the evidence of a general northward drift hugging the Nova Scotian side of the gulf to the Bay of Fundy, and of its continuation westward as far as Penobscot Bay, is made cumulative by these drifts into the gulf.

The Brazil Rock series of 1926 also show the following seasonal succession: In July and August the dominant movement from the offing of Cape Sable was into the Gulf of Maine, but by the end of September the Scotian eddy had spread westward far enough to involve some bottles from this line in drifts best interpreted as circling anticlockwise, first offshore and then in again to the coast, to the eastward.

Further details as to the tracks followed are to be expected in Doctor Huntsman's forthcoming account.

One other bottle is recorded by the United States Hydrographic Office (Pilot Chart for May, 1923; reverse No. 26) as showing a similar drift into the eastern side of the Gulf of Maine from its release, 34 miles south of Cape Sable, September 21, 1902, to its recovery near Yarmouth, Nova Scotia, 30 days later.

CIRCULATION OF THE SUPERFICIAL STRATUM AS INDICATED BY SALINITY

The distribution of salinity affords a valuable check on the correctness of the circulatory system of the surface stratum, deducible from the drift-bottle experiments and from current measurements. The physical state of the water, together with the horizontal and vertical distribution of density, is the only clue yet available to the nontidal circulation in the deep strata of the gulf.

The reader will find frequent references to this phase of the subject in the section devoted to the salinity (p. 701). The distribution of salinity, as a reflection of the circulation of the gulf, has also been discussed in such detail in earlier reports on the Gulf of Maine explorations (Bigelow, 1914 to 1922) that a brief statement will suffice here.

With the oceanic water outside the edge of the continent much salter than the water in over the banks or alongshore (a rule prevailing all along eastern North America from Florida to the Grand Banks) a high salinity becomes an excellent indicator of any indraft from offshore. On the other hand, the lines of dispersal for land water are to be learned from the distribution of the least saline water. In the Gulf of Maine the flow of the Nova Scotian current past Cape Sable also tends to freshen the surface wherever its influence reaches.

Our first summer's cruise (in 1912) was enough to show what subsequent cruises have corroborated, that the freshest water is not localized off the mouths of the several large rivers, as would be the case if the discharges from these simply fanned out, but that it takes the form of a continuous and comparatively narrow belt skirting the coast line. The region where this freshest water does spread farthest out to sea (off Cape Ann and Massachusetts Bay) is some distance southward from the mouth of the Merrimac, the nearest of the large rivers. No fan of low salinity has ever been demonstrated off the mouth of the Kennebec.

The absence of such a fan off the mouth of any given river may or may not prove the failure of its discharge to drift out to sea, depending on the balance between the activity with which the tides mix the deep with the surface strata there and the volume of fresh water discharged. The river water that runs into the northern side of the gulf, and especially into the Bay of Fundy, is rapidly consumed in this way. Nevertheless, even where mixing is most active, areas of relatively lower salinity off the river mouths might be expected to alternate with areas relatively higher in salinity along the coast sectors between them, unless some dominant drift in one direction or the other disturbed this idealized picture. When we recall how great a volume of fresh water actually pours into the Gulf of Maine every year (p. 837) it is hardly conceivable that it would exert its chief freshening effect on so narrow a coastwise belt, unless the surface water tended to drift parallel to the land in the one direction or the other.

The summer salinities of 1912 (p. 770) pointed very clearly to a longshore movement of this sort around the northern and western margins of the gulf, setting westward along the coast of Maine, southward to Cape Ann, and spreading eastward off the cape in a rather definite tongue, outlined (at the surface) by the isohaline for 31.8 per mille (Bigelow, 1914, pl. 2). It was the presence of this tongue which established the direction of flow beyond dispute, because considerably higher salinities in Massachusetts Bay to the south of it, as well as offshore, left the coastal belt to the northward as its only possible source.

On the other hand, the salinity of the surface then afforded little evidence of river water in the northeastern corner of the gulf, in spite of the proximity of the St. John River. This, however, can be explained by the active mixing that takes place there, for while the mean salinity of the upper 50 to 60 meters was slightly higher (about 32.5 per mille) in the Grand Manan Channel and at its western end that August than it had been at the mouth of Massachusetts Bay a month earlier (about 32.2 per mille), the difference is no greater than can be explained as due to the regular seasonal succession (p. 799). A detailed discussion of the salinities for that summer, given in an earlier report (Bigelow, 1914, p. 90), leads to the conclusion that water of high salinity was being drawn into the eastern side of the gulf while the coastwise belt was dominated by a nontidal set alongshore from north and east to south and west, with expansions of water of low salinity off Penobscot Bay and off Cape Ann suggesting two separate anticlockwise eddies.

The subsequent summer cruises have expanded this preliminary concept of a general circling movement around the northern and western shores of the gulf to the domination of the surface over the entire basin by a great anticlockwise eddy, paralleling the land northward along Nova Scotia and swinging westward and then southward toward Cape Cod (Bigelow, 1917, p. 340), this being the only assumption on which the distribution of surface salinity can be rationalized.

This, it will be noted, has since been corroborated by the bottle drifts just described. A comparison between the recurving tongues of low salinity off Cape Ann and off Penobscot Bay, when such phenomena develop there, with the drifts from the Mount Desert, Cape Elizabeth, and Cape Ann lines, is especially instructive, for we find in such tongues a rational explanation for the tendency of the bottles to veer out from the land on successive radii. If, for example, bottles had been put out off Mount Desert in the summers of 1912 or of 1913, salinity suggests that the majority would have turned southward, abreast of Penobscot Bay, and that few, if any, would have stranded along the coast farther west. This actually happened in 1923 (p. 902, fig. 183). The tendency for bottles put out near land on the Cape Elizabeth and Cape Ann lines of that year to veer offshore from the beginning of their drifts would similarly find a reasonable cause in expansions of low salinity out toward the basin from the offing of Cape Ann, such as were actually recorded in July, 1912, and in August, 1914 (p. 763, fig. 136). But the distribution of surface salinity in August and September, 1915, when scattered observations outlined a band of low salinity of comparatively uniform breadth as paralleling the coast line from Nova Scotia to Cape Ann (fig. 137), would be compatible with drifts hugging the shore more closely as far as the cape, or perhaps to Massachusetts Bay, such as were actually followed by bottles set out in the Bay of Fundy during the summer of 1919 (p. 870) and off Cape Neddick (series O) in July, 1926. The locations of the isohalines at the surface are thus entirely reconcilable, both with the drifts assumed for the bottles and with the annual difference indicated by the sets put out in the summers of 1919, 1922, 1923, and 1926.

Mavor (1923), in his discussion of the distribution of salinities and temperatures in the Bay of Fundy for August, 1919, has shown that these are best explained as due to a movement of water into the bay on the Nova Scotian side, recognizable from the surface down to a depth of 100 meters, crossing northward toward New Brunswick about midway up the bay, with a counterbalancing outflow of water of low salinity southward and westward along the northern (New Brunswick) side. Here, again, temperature and salinity corroborate the evidence of drift bottles (p. 870).

The high surface salinities recorded in the northeastern corner of the gulf on the August cruises of 1912 and 1913 suggested a continuous tongue of highly saline water flowing into the eastern side of the gulf at the surface from the Atlantic Basin. However, subsequent discovery that the high surface values encountered in the basin between Maine and Nova Scotia in successive summers actually represent an isolated pool, resulting from local upwelling combined with tidal stirring (p. 768), and surrounded by less saline water on all sides, has lead to the appreciation that the gulf receives its saline water chiefly in the deeper strata (p. 842), not on the surface.

The rather abrupt west-east transition in surface salinity registered in the offing of Cape Sable in the summers of 1914 and 1915, added to the retreat of the critical isohalines (32 to 31.5 per mille) from the eastern side of the gulf, eastward, with the advance of the spring (p. 755), argues against any notable current from the east past the cape as characteristic of summer. Here, however, the effect which the active tidal mixing southwest and west of the cape would have in increasing the salinity of the surface, moving westward, must be taken into account.

If the evidence of salinity does not make clear the dominant set, if any, past Cape Sable for the summer months, the tongue of low salinity and low temperature found extending along the southeastern face of Georges Bank from northeast to southwest in July, 1914 (p. 770), is "hard to explain, except as an outflowing current from the gulf" (Bigelow, 1917, p. 241); and though this may not be a regular feature of the summer circulation (p. 608), the fact that several bottles from the Cape Cod and Cape Ann series of 1922 and 1923 seem to have drifted out of the gulf via this same route across the eastern end of Georges Bank (figs. 174 and 176) is certainly suggestive of its permanency. A tendency for water of low salinity to spread from the vicinity of Cape Cod southeastward to the neighboring part of Georges Bank is also indicated by the contrast in salinity between the western and eastern ends of the latter on the summer chart for 1914 (fig. 136, isohaline for 32.2 per mille). Here, again, a close parallel appears from the set, as indicated by the salinity of the surface water and the probable drift tracks of bottles that went in that direction from the Cape Cod series of 1922 (series B, p. 880, fig. 174). Farther south, in the southwestern part of the area, successive isohalines for 32.5 to 33.5 or 34 per mille, closely crowded and roughly paralleling the edge of the continent, prove that the dominant set here is along the outer part of the shelf, not transverse to it, though with some tendency indicated toward an eddying movement northward toward the land to the west of Nantucket Shoals. All this, again, is at once reconcilable with the drifts of bottles set out in this side of the gulf, especially with the tracks eddying westward out of the gulf past Nantucket Shoals, and with the group that went west from the edge of the continent abreast of Cape Cod (series B, outer end, p. 882).

The failure of any evidence, by salinity, of a surface drift from the continental edge out into the ocean basin in the region, in any summer of record, is corroborated by the fact that from the outer end of line B (fig. 174) only four bottles are known to have reached the general North Atlantic drift, and so to have gone across, one to England, one to Ireland, the other to the Canary Islands and the Azores.

The distribution of salinity at a depth of 40 meters has proved extremely diagnostic of the dominant circulation of the gulf, even more so than at the surface, the chart for July and August, 1914 (fig. 145), being the most instructive because covering the area as a whole. Its most noticeable feature—a continuous tongue of water of high salinity (33 to 33.4 per mille), extending from the Eastern Channel and Browns Bank inward to the north along the eastern side of the basin as far as the mouth of the Bay of Fundy—obviously reflects an unmistakable set of water into the gulf from the edge of the continent. The surface charts, the reader will recall, show nothing of this sort, evidence that the inward current (the existence of which is proven by several lines of evidence) did not involve the superficial stratum. Neither does it draw direct from the oceanic water (which would swing the isohalines for 34 to 35 per mille into the Eastern Channel), but from the mixture that takes place between tropic water and the water of the banks along the edge of the continent abreast of the gulf (p. 842). So far as the contour of the bottom is concerned, the whole southern aspect of the gulf, from Nantucket Shoals to the vicinity of Cape Sable, is open to overflows from this same source down to a depth of 40 meters.[82] Actually, however, we have found no evidence, in salinity, of any indraft of this sort anywhere to the westward of the Eastern Channel.

The expansion of the isohalines for 33 and 32.9 per mille to the westward along the coast of Maine, and the course of the isohaline for 32.5 per mille on the 40-meter chart just mentioned (fig. 145), combined with the location of the saltest tongue close against the eastern slope of the basin, are most readily reconcilable with a dominant set northward in the eastern side of the gulf (complicated by the evidences of upwelling in the offing of the Bay of Fundy already mentioned on p. 768), veering westward along the coast of Maine, and so southward around the periphery of the gulf, finally to turn southeastward as it is directed toward Georges Bank by the slopes of Nantucket Shoals.

This essentially reproduces the anticlockwise eddy indicated by the distribution of salinity at the surface (p. 911) as well as by the bottle drifts (p. 906), but the fact that the highest salinities at 40 meters lie 10 to 20 miles out from the 40-meter contour line in the eastern side of the gulf, not close in against the latter, is evidence that the eastern side of the eddy lay farther and farther out from the Nova Scotian

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[82] Except for the shoals on Georges Bank.

coast at increasing depths in 1914, as was also the case in August, 1913 (fig. 146). The comparative uniformity of salinity recorded over a wide area in the western side of the gulf at the 40-meter level in August, 1914, contrasted with the definitely outlined tongue of high salinity in the eastern side, points to the north-flowing side of the eddy as much more definite than the south-flowing side. In August, 1913, however, the distribution of salinity at 40 meters pointed to a closer approach to equality between the two sides of the eddy. The drift is not as clearly shown by the 40-meter salinities taken in August and September, 1915 (p. 990), except that the differential between higher salinities in the eastern side and lower ones in the western side of the gulf calls for some movement of the same anticlockwise sort, not being wholly explicable on the basis of upwelling, though assisted by that process (p. 768).

In none of these years (1913, 1914, and 1915) did the 40-meter level show the expansion of water of low salinity off Cape Ann that involved the upper 40 meters in July, 1912 (Bigelow, 1914, pl. 2; isohaline for 32.6 per mille at 25 fathoms), in a definite easterly drift. Thus, the distribution of salinity reflects much more variation, from summer to summer, at the 40-meter level in the western side of the gulf than in the eastern side, as well as at the surface (p. 770).

Unfortunately, the 40-meter chart for 1914 (fig. 145) does not so clearly show the dominant movement of water in the southwestern part of the area. However, isohalines closely crowded outside the 100-meter contour and the fact that they run parallel to the latter make it certain that no general drift was taking place transverse to the edge of the continent at the time, but that any dominant set that was then active roughly paralleled the latter. Consequently, the broad zone of 33 to 34 per mille between it and Nantucket Shoals (much more saline than any part of the Gulf of Maine at this level, but less so than the tropic water outside the continental edge) did not reflect a direct encroachment of the latter at the time or even any such movement earlier in the season, but merely reflected (by its precise salinity) the proportionate amounts in which water of higher and lower values had mingled there. However this may be, the presence of water of this comparatively high salinity to the south and southwest of Nantucket Shoals, added to rather an abrupt transition to considerably lower values (about 32.8 per mille) on the neighboring parts of Georges Bank, is good evidence that the surface drift, which has carried so many bottles out of the gulf westward across or around the shoals (p. 881), was not then operative to as great a depth as 40 meters, but that it is deflected more to the eastward, as the depth increases, by the contour of the bottom. This suggestion is corroborated to some extent by the fact that the isohalines for 33 per mille or lower include the whole eastern end of Georges Bank on the 40-meter chart in question, with an abrupt transition to much higher salinities (34.5 to 35 per mille) off its southeastern slope.

At first sight the presence of a tongue of water warmer than 10° running obliquely across Georges Bank from southwest to northeast at the 40-meter level, with lower temperatures within the gulf to the north as well as along the southeastern face of the bank (fig. 53), might seem to contradict this, but in this case salinity is the more reliable index to circulation, because the high 40-meter temperature at the station in question (10224), associated as it was with correspondingly low temperature (11.1°) at the surface, simply reflected active vertical mixing by tidal currents. Any tendency for the water to move from west to east over Georges Bank would necessarily be diverted by the considerable area shallower than 40 meters in which the bank culminates.[83] According to the rule general in the Northern Hemisphere, this shoal might be expected to act as the vortex for a clockwise circulatory movement, and the fact that the 40-meter salinity was somewhat lower on the eastern side of the bank than on the western side at the time, with the transition from values lower than 32 per mille to higher than 34.5 per mille most abrupt off its southeastern slope, is evidence of such a drift eddying eastward and southward around the shoal area.

The dominant circulation of the gulf is most clearly reflected in salinity at the time of year (spring and summer) when the regional variations in this respect are widest.

The progressive equalization of salinity that takes place during the autumn (p. 799) makes it increasingly difficult to reconstruct the horizontal circulation, even in its broadest aspects. In the midwinter of 1920–21 salinity yielded no definite evidence of any indraft into the eastern side of the gulf, either at the surface or at 40 meters (p. 804). It is unfortunate that observations could not be taken off Cape Sable during this midwinter cruise, for without such it is impossible to state whether the low values (31.2 to 31.3 per mille) recorded near Yarmouth, Nova Scotia, on January 4 (station 10501) reflected any movement of water past the cape from the eastward or were simply the product of local drainage from the land. However, it is certain that still lower salinity at the surface a few miles south of the Merrimac River, across the gulf, a few days earlier (30.02 per mille at station 10492) had the latter origin, and the rather abrupt transition appearing in both sides of the gulf on the surface chart (fig. 163) between water of low salinity (<31.5 per mille) close in to the land and considerably higher values (32.5 per mille) a few miles out at sea is definite proof that this coast belt was (or had been) drifting parallel to the shore line (if at all), not spreading inshore or offshore in either side of the gulf. However, the fact that the surface belt less saline than 32.3 per mille was much broader abreast of Penobscot Bay than in the offing of Casco Bay, on the one side, or off Mount Desert, on the other, points to some slight tendency for the water to drift out from the coast off the former, such as appears more definitely in the summer isohalines for 1912 (p. 770). Some such eddying movement is also indicated by the undulatory course of the isohalines off the mouth of the Bay of Fundy, suggesting a movement of water of low salinity out of its northern side toward the southwest, but no observations were taken close enough to the Nova Scotian side of the bay to develop the inward drift to be expected there.

The data for deeper levels were not distributed generally enough over the gulf during the midwinter cruise for safe interpretation in terms of dominant drift.

In early spring, when the discharges from the rivers increase, the courses of the isohalines become much more instructive with respect to the dominant drift, because they give a trustworthy clue to the lines of dispersal of the fresh water from the land. One of the most interesting phenomena in the hydrographic cycle of the gulf is the

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[83] Minimum depth about 6 meters.

tendency of this water to hug the coast, not to fan out over the basin. At certain points along the coast local fishermen have long been aware that this results in a considerable southwesterly drift parallel with the coast, so much so that it is locally named the "spring current." The progressive development of a coastwise band of low salinity, which results from this event, is well illustrated by the successive surface charts for March and April, 1920 (figs. 91 and 101). Such distribution as appears on the latter and on the corresponding chart for May (fig. 120) could persist only with the water of the coastwise belt setting parallel to the general trend of the northern and western coast lines of the gulf, as already explained (p. 910). In the same way the expansion of water less saline than 32 per mille southward from the northern margin of the gulf, along its western shore, in a narrow band past Cape Ann to Massachusetts Bay, from March to April, and so out past Cape Cod toward Georges Bank by May (fig. 120), is unmistakable evidence of a general set of the surface water around the coast line along this same route.

The evidence afforded by salinity is therefore clear to the effect that when the outpouring of land water is at its maximum in spring it parallels the land, with a dominant flow alongshore from east and northeast to southwest and south, instead of spreading seaward, as happens off river mouths in many parts of the world. In other words, when the velocity of the left-hand side of the Gulf of Maine eddy is greatest it hugs the shore closest. The abrupt transition from surface salinity lower than 30 per mille to higher than 32 per mille, recorded 15 to 20 miles out from the western sector of the coast line between Cape Elizabeth and Cape Ann in May, 1915, gives a rough indication of the breadth of the zone along which the combined discharges from the Kennebec, Saco, and Merrimac Rivers are carried when the latter are in flood; and some indication that the main axis of this "spring current" is directed southward across the mouth of Massachusetts Bay, with some tendency to veer westward around the coast line of the latter after it passes Cape Ann, is traceable on the surface charts for April and May, 1925 (figs. 102 and 119), as noted above (p. 743). In this respect salinities and the drifts of bottles set out in Ipswich Bay (p. 890) prove mutually corroborative.

The charts of surface salinity for late summer for the several years, combined with the bottle drifts, suggest that the northern and western sides of the dominant eddy may be expected to trend more out from the land as the summer advances; but the isohalines point to considerable differences in this respect in different years, as just described (p. 770).

The chief line of dispersal for the discharge from the St. John River is located as tending toward the southwest past the eastern side of Grand Manan, by the sudden freshening of the surface recorded by Mavor (1923) at *Prince* station 3 from April to May in 1917 (p. 808; fig. 165), agreeing, again, with the routes probably followed by the bottles that drifted out of the bay in 1919 (p. 870); but the increase in salinity that takes place at this location from May to June and July is evidence equally positive that the velocity of this drift is at its maximum for only a few weeks (perhaps only a few days), though some movement of the surface water probably takes place in this direction throughout the year (p. 973).

The most interesting aspect of the seasonal dislocations of the isohalines in the southeastern part of the Gulf of Maine area is the light they throw on the fluctuations and lines of dispersal of the Nova Scotian current while this is flowing into the gulf from the eastward. The source of this cold water of low salinity and the chilling effect it exerts on the gulf are discussed in another chapter (p. 825), leaving for present consideration the rôle it plays in the dominant circulation of the gulf.

No dominant current of any great volume is demonstrable past Cape Sable in either direction from the salinities for August or September (though bottle drifts show the movements of water stated in another chapter—p. 908), nor in March (fig. 91); but when the Nova Scotian current commences to flood westward into the gulf in spring, its freshening effect is unmistakably reflected by a very noticeable dislocation of the critical isohalines (32 and 32.5 per mille). The seasonal schedule of this event varies from year to year, as described on page 832, 1920 being late in this respect, 1919 early, but experience in those years and in 1915 suggests that as the flow of the Nova Scotian current increases to its greatest head, it may be described as sweeping the isohalines westward before it far out into the gulf.

Unfortunately, our May cruise of 1915 did not extend to the southeastern part of the gulf, nor did the Canadian Fisheries Expedition take observations west of Halifax during that month, which leaves a wide gap for which I can not attempt to reconstruct the courses of the isohalines. However, the curves for 32 per mille salinity at the surface and at 40 meters (figs. 120 and 125) both outline the current as spreading westward from the cape toward the center of the gulf and somewhat fanlike toward the north.

This is corroborated by the fact that the *Grampus* encountered a strong set to the westward, upwards of 2 knots in velocity, on her run from the eastern side of the basin (station 10270) toward Seal Island, off Cape Sable (station 10271), on the 7th of that month. In that year, however, which may be taken as representative, the surface isohaline for 32 per mille had again withdrawn a considerable distance eastward toward Cape Sable by the last week in June (fig. 128), evidence that the westerly drift across the basin of the gulf ceased as soon as the flow of the Nova Scotian current slackened. The general distribution of salinity that characterizes the eastern side of the gulf in summer (p. 765) is best explained on the assumption that any water that rounds Cape Sable from the east during the months of July, August, and September veers northward along Nova Scotia toward the bay of Fundy, which is in accord with the drifts of the bottles that have entered the gulf from the east (p. 908).

It is obvious that the western extension of the Nova Scotian current must profoundly affect the nontidal circulation of water in the gulf at the season when it is at its maximum. Comparison of the surface salinity in May (fig. 120) with the currents deduced from bottle drifts in August suggests that this change consists chiefly in shifting the eastern side of the Gulf of Maine eddy westward—how far, can not yet be stated.

It is also obvious that if the the anticlockwise eddy persists through spring (as there is ample evidence, theoretic as well as direct) it must constantly draw into its eastern side (and so carry northward toward the Bay of Fundy and the coast of

Maine) an admixture of the colder and less saline water from the Nova Scotian current; but the details of this process and the extent to which it influences the temperature, salinity, and circulation of the northeastern part of the gulf can not be worked out until more data are gathered for the critical months of May and June.

It is much to be regretted that no records on the eastern part of Georges Bank have been obtained for June, which might throw light on the expansion of Nova Scotian water in that direction; but the fact that we have found the surface salinity considerably higher in the Eastern Channel and in the basin of the gulf near by than from Browns Bank in to Cape Sable, both in June and in July (figs. 128 and 136), shows that any movement that may take place along this zone toward the southwest in spring had ceased by the beginning of the summer both in 1914 and in 1915.

CIRCULATION OF THE SUPERFICIAL STRATUM AS INDICATED BY TEMPERATURE

The distribution of temperature is by no means as clear an index to the nontidal circulation of the surface waters of the gulf as is its salinity, because any given mass of surface water may be warmed rapidly by the sun or cooled by radiation when the overlying air is the colder without suffering any alteration in its identity by mixture with other water masses. In the deep strata, however, which are more or less insulated from these thermal influences from above, regional differences in temperature are more easily interpreted in terms of circulation.

The relationship of temperature to circulation is referred to repeatedly in other connections;[84] only the most salient aspects, then, need be referred to here.

The belt of coldest water, which fringes the shores of the gulf in winter, owes its low temperature to the chilling effects of the icy winds that blow out over it from the land. The fact that this cold band (as illustrated by the surface charts for midwinter (fig. 80) and for February to March—fig. 1) is comparatively uniform in breadth all along the northern and western shore line, is best reconciled with a set paralleling the shore. Any considerable movement of surface water either from the land out to sea or vice versa would give much more undulatory courses to the critical isotherms of 5° in December to January and 2° in February to March.

Surface water equally cold over the Northern Channel and Browns Bank on the February to March chart (fig. 1), giving place, by a rather abrupt transition, to readings 1.5° higher over the Eastern Channel, reflects the westernmost bound of the Nova Scotian current at the time; and an expansion of water colder than 4° out over the channel from the the gulf and across the eastern end of Georges Bank but not across the western end of the bank is evidence of a movement in that direction, which corresponds to the drifts of bottles set out off Cape Cod in summer (p. 886).

The undulatory course of the March isotherm for 3° gives a rather clear indication of an anticlockwise eddying movement in the central part of the gulf, with warmer water moving northward in the eastern arm of the basin and colder water drifting out from the land off Penobscot Bay, illustrating one of the varying forms

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[84] See the chapter on temperature.

of the Gulf of Maine eddies. This same distribution of temperature, however, reappearing in April, is reminiscent of a past state of circulation, not of a present one, because the corresponding charts of salinity show the dominant set to have assumed a southwesterly course, more nearly parallel to the coast line, from the one month to the next (p. 743). Neither of these early spring charts of temperature suggest any drift of warmer water into the eastern side of the gulf from offshore; but some drift of this sort is indicated on the 40-meter chart for March (p. 525) by a band warmer than 3° entering via the Eastern Channel. This indraft appears more clearly at deeper levels (p. 526).

With the advance of spring the regional inequalities of temperature become increasingly significant, from the standpoint of circulation, as they outline the lines of dispersal followed in the gulf by the cold water of the Nova Scotian current. In general, temperature corroborates salinity to the effect that the current did not begin to flood westward past Cape Sable until after the middle of April in the year 1920, though it had exerted its chilling effect in this direction as far as the eastern side of the basin of the gulf by the last of March the year before (p. 553). The isotherms for May (fig. 27), however, suggest more of a tendency for this Nova Scotian water to spread northward toward Maine and the Bay of Fundy, as well as westward in the gulf, when at its head, than do the isohalines (p. 745).

Rising temperature, like rising salinity, reflected a slackening in the current in 1915 from May to the last half of June, when an abrupt transition in the temperature of the coldest stratum, from the Eastern Channel (about 8.1°) to the vicinity of Cape Sable (about 0.7°), located its southwestern boundary at Browns Bank. This is also indicated by the abrupt transition from colder to warmer water along the western slope of the bank at 40 meters; but the low temperatures recorded over the southwest slope of Georges Bank on the July profile for 1914 (fig. 58, p. 616)[85] is readiest explained as reminiscent of a cool current skirting the bank from northeast to south some time previous. It seems that in the cold year 1916 such a drift of cool water was either in much greater volume or persisted until later in the season, for it is difficult to account otherwise for the band of low temperature which the *Grampus* encountered over the southwestern slope of the bank that July (p. 629).

"The facts that the cold band of 1916 lay almost exactly in the prolongation of that of 1914; that a similar streak of comparatively low temperature (6.4°) was encountered at the same relative position on the shelf some 60 miles farther west in 1913 (station 10062); and that the axis of the coldest water noted on the shelf south of Nantucket in 1889 (Libbey, 1891) merely prolongs this general zone, practically amount to proof that a northeast to southwest flow of cold water takes place there annually in late spring or summer, dovetailing in between the warmer and fresher bank water on the north and the Gulf Stream on the south." (Bigelow, 1922, p. 166.) Its source is discussed elsewhere (p. 848). The July isotherms for 1914 locate its extreme western boundary between longitude 68° and 69°, where the 40-meter chart

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[85] This also appears on the corresponding chart for the 40-meter level, but is complicated there by active vertical mixing that maintains a higher temperature over the shoal parts of the bank at this depth (lower at the surface) than on its southern side; the alternation of a warm with a cold belt along the bank, outlined in the 40-meter chart (fig. 53), is therefore partly of local origin.

(fig. 53; isotherms for 10° and 12°) suggests an eddying movement, drawing warmer water inward over the bank on the western side; but in other summers the cool drift extends much farther westward. Bottle drifts, for example, place 1922 in this category (p. 883); and Libbey (1891 and 1895) records it in longitude 70° to 71° in the summer and early autumn of 1889.

In another chapter (p. 585) I have tried to make it clear that the areas of low and high surface temperature, which characterize various parts of the Gulf of Maine in summer, are due chiefly to tidal stirring—most active over the shoal banks and in the northeastern part of the area generally, least so in the basin off Massachussetts Bay. Tidal stirring also plays a part in holding the surface temperature somewhat lower along the western margin of the gulf and around the shore of Massachussetts Bay than a few miles out at sea; but the gradation also points to some movement of the surface water eastward, away from the shore, under the impulse of the prevailing southwestern winds, an event with which bathers on our beaches have long been familiar (p. 588), and which takes part in the development of the western side of the Gulf of Maine eddy. The evidence (by bottle drifts) of a westerly set from the Nova Scotian side and from the Bay of Fundy along the coast of Maine is also borne out by the extension of surface water colder than 14° westward past Penobscot Bay in August (figs. 46 and 47) over depths so great that tidal stirring, *in situ*, is not active enough to be responsible, *per se*, for surface values as low as those actually recorded there.

The 40-meter charts for July and August (figs. 52, 53, and 54) also suggest a similar westerly drift by the isotherms for 8° and 9°, though at this depth the water moving in that direction from the Nova Scotian side is warmer than that which it replaces off the coast of Maine—not colder, as it is at the surface. or discussion of this bathymetric difference, see p. 608).

The mutual relationships of waters warmer and colder than 9° were especially suggestive in August, 1913, as locating the vortex of the anticlockwise eddy about 60 miles south of Mount Desert and Penobscot Bay (fig. 52). The corresponding chart for 1914 (fig. 53) is not so easy to interpret in this respect, the picture being complicated in the western side by a pool of water cooler than 6°, which probably owed its low temperature to vertical stirring or to local upwelling in the mid depths.

None of the summer charts for temperature reveals any dominant movement of warm water into the gulf from offshore at the surface, nor do the 40-meter charts for the summers of 1914 or 1915, but some circulatory indraft of this sort is suggested on the 40-meter chart for 1913 (fig. 52) by temperature, just as it is by salinity (p. 782), by the warm (>10°) tongue in the eastern side of the basin, with lower temperatures on either hand, to which the reader's attention has already been called (p. 608).

At first sight the distribution of temperatures at 40 meters prevailing in July, 1914 (fig. 53), might suggest a drift into the gulf from offshore across the eastern end of Georges Bank, but a closer analysis makes it clear (p. 617) that in this case unity of temperature had a local significance only, being an adventitious result of the fact that vertical mixing was most active on the northern part of the bank.

CIRCULATION IN THE DEEP STRATA AS INDICATED BY TEMPERATURE AND SALINITY

Dawson's (1905) observations made it known that the tidal currents of the eastern side of the gulf run about as strongly down to a depth of 55 meters as they do at the surface, and measurements taken at 5 stations by the *Grampus* in the summer of 1912 showed bottom currents varying in velocity from 0.1 to 0.25 knot per hour in depths of 100 to 265 meters (Bigelow, 1914, p. 86). Evidently, then, the basin of the gulf is constantly in a state of active circulation right down to the bottom, its whole mass of water oscillating to and fro with the tides, though with velocities somewhat lower in the deep water than at the surface.

Up to the present time no attempt has been made to determine the nontidal movement of the bottom water of the gulf with current meters or by the use of deep drift bottles, such as have proved so instructive in the North Sea, but the regional differences in temperature and salinity outline the major movements over the bottom.

At depths greater than 100 meters the gulf of Maine is an inclosed basin with the narrow Eastern and Northern Channels as the only possible entrances or exits through which water can flow in or out of its basin. It follows from this that any deep current into the gulf can enter only in its eastern side. Such entrance might be via either of the two channels or through both, so far as the contour of the bottom is concerned. Actually, however, salinity and temperature show that the indraft of slope water over the bottom is restricted to the Eastern Channel, the abrupt west-east transition in salinity and in temperature, which characterizes the Northern Channel, being incompatible with any large transference of bottom water through the latter in either direction.

The dominant drift in the eastern side of the Eastern Channel is clearly northerly (into the gulf) at all times of year, but a considerable difference between high values of temperature and salinity in the eastern side of the channel and lower values in its western side in March, April, and July (pp. 770, 789) point to an outflowing current via the latter, continuing southward and westward around the slope of Georges Bank.

Slope water is betrayed in the deep strata of the gulf by its high salinity (33.5–34 per mille, p. 849) and moderately high temperature (4.5° to 8°). At the 100-meter level the isotherms and isohalines show the inflowing current hugging the eastern slope of the basin in March as a rather definite tongue of high temperature and salinity (figs. 13 and 94), veering westward around the northern side of the basin, with a countermovement of cooler and less saline water setting southward and eastward around the southern side of the basin. In fact, physical evidence could hardly be clearer that the general Gulf of Maine eddy was effective to a depth of at least 100 meters in this particular month, though complicated by an indraft through the Eastern Channel in the deeper levels, which did not directly affect the surface (p. 704).

An anticlockwise circulation is also indicated on the 100-meter charts for April (figs. 25 and 116), though less clearly, by concentration of the highest salinities and temperatures in the eastern and northern parts of the basin, the lowest in the western and southern parts. In this case, however, the westerly component involved a broader and less definite band off the coast of Maine than in March, and the easterly component of the eddy had shifted southward to skirt the northern slopes of Georges Bank more closely.

Information as to the movement of water along the bottom of the Northern Channel is much to be desired at the season when the Nova Scotian current is flooding in greatest volume into the gulf. Some drift may be assumed to take place into the gulf by this route as deep as 100 meters in 1915, to account for the concentration of the most saline water in the western side of the basin at the 100-meter level in May (fig. 127), instead of in the eastern side, as at other times of year. It is probable, therefore, that when the drift past Cape Sable is at its maximum it causes a westerly shift in the vortex of the general eddy in the mid depths, though not essentially altering the anticlockwise type of circulation, however. Any westerly drift that may have taken place along the bottom of the Northern Channel in 1915 had ceased by June; on this basis, alone, is the abrupt east-west transition that appears there on the 100-meter chart of temperature for that month explicable (fig. 43).

In midsummer the transition from lower salinities and temperatures in the western side of the gulf to higher in the eastern, at the 100-meter level, and the sweep of the successive isohalines and isotherms from east to west along the northern slope of the gulf, again give evidence of a general set northerly past Nova Scotia and westerly along the coast of Maine in the mid depths, paralleling the dominant circulation at the surface. The nontidal movement of water of the southern side of the basin at this level is not so clear, the picture being confused by an area of relatively high salinity and temperature off the northern slope of Georges Bank near the entrance to the Eastern Channel, which is not easy to account for.

In spite of this and of other apparent anomalies the distribution of temperature and salinity in the mid depths, as exemplified by the 100-meter level, are, as a whole, compatible with the domination of the basin by the general Gulf of Maine eddy, anticlockwise in character.

The horizontal circulation of the gulf at greater and greater depths is more and more directed by the contour of the bottom, which gives the basin the outlines of a Y, with two arms uniting and open to the Eastern Channel (p. 784) at 175 meters, but entirely inclosed at 200 meters and deeper.

With temperatures and salinities recorded at one deep station or another for so many months and years, it can be stated confidently that the movement of bottom water inward into the gulf takes place in pulses, the secular fluctuations of which have only been glimpsed as yet (p. 850). On the other hand, dynamics (fig. 204) and the distribution of temperature and salinity point to some outgoing drift via the western (Georges Bank) side of the Eastern Channel between these pulses in summer (pp. 789, 852).

The presence of water of high salinity (34 per mille) in both arms of the trough but never (so far as yet recorded) over the submarine ridge that separates them is good evidence that the latter divides the slope water as it drifts inward in the deepest stratum of the gulf.

Two separate anticlockwise eddying drifts are indicated in the bottoms of the two arms of the trough, at depths of 175 meters and deeper, by salinities and temperatures averaging somewhat higher on the side that would be to the right, for an inflowing current, than on that to the left (p. 785). The circulation in each may therefore be described as "estuarine," subsidiary to the estuarine circulation of the basin of the gulf as a whole, inward along the right-hand (eastern and northern) sides and eddying to the left. The regional difference between the right and left sides being widest in the eastern trough, with the maximum values of salinity and temperature both higher there than in the western, a greater volume of slope water continues northward over the bottom toward the Bay of Fundy (and at a greater velocity) than is diverted to the westward by the ridge that culminates in Cashes Ledge.

CIRCULATION AS INDICATED BY THE PLANKTON

The tracks which immigrant members of the planktonic community follow into the gulf and in their further wanderings within it are discussed in such detail in the preceding number of this volume (Bigelow, 1926, p. 51), to which the reader is referred for details, that the briefest of summaries will suffice here. Immigrants of this category, whether from tropic or from northern sources, enter the gulf in the eastern side; seldom or never across its offshore rim farther west. (Bigelow, 1926, figs. 31 32, 33, 69, 71, and 72.) The relative regional abundance of our northern copepods, *Calanus hyperboreus* and *Metridia longa* (Bigelow, 1926, figs. 71 and 76), clearly pictures the drift westward into the gulf from the offing of Cape Sable and westward along the offshore slope of Georges Bank in the spring; and the records for the more delicate northern visitors—Mertensia, Ptychogena, *Oikopleura vanhöffeni*, and *Limacina helicina*—are chiefly confined to the area on the eastern side, where the water is most chilled by the Nova Scotian current.

Clearest evidence of the drift within the gulf is afforded, of course, by such species as are comparatively short lived there and can not reproduce in its low (or high) temperature. The records for these in the upper 40 meters or so have been constantly confined to a rather definite belt paralleling the coast around from the Nova Scotian side to the offing of Massachusetts Bay, leaving the central and southern parts of the gulf bare (Bigelow, 1926, fig. 31). A distribution of this sort is reconcilable with an eddying drift inward, anticlockwise around the gulf; in fact, it is explicable on no other reasonable assumption, and this corroborates the drift-bottle experiments. A drift of this same sort from the coast of Maine westward and southward toward Cape Cod is also made probable by the relative distribution of buoyant fish eggs and of larval fishes (Bigelow, 1926, figs. 34 and 35). Planktonic animals that enter the gulf in the mid levels via the Eastern Channel (*Eukrohnia hamata*, for example) parallel the surface communities in their general drift northward, westward, and southwestward, except that they are held farther out in the basin by the contour of the bottom; but visitors characteristic of the deepest water of the gulf (e. g., *Sagitta maxima*) follow the two arms of the Y-shaped trough, just as might be expected from the drift of the slope water, as indicated by the salinity (p. 922).

The comparative scarcity of animals of coastwise or shoal-water origin over the deep basin of the gulf (Bigelow, 1926, p. 32), like the distribution of salinity, is evidence of a circulatory system paralleling the coast, not fanning out in the offing of the river mouths.

VERTICAL STABILITY AS AFFECTING THE CIRCULATION OF THE GULF

A clue to the relative strength of vertical currents in different parts of the gulf during the warm months is afforded by the relative degree of vertical stability of the water that opposes them.

The relationship between vertical circulation and stability is simple. Whenever or wherever the water is so nearly homogeneous as to the density that it has little or no vertical stability (as is the case in the coastwise belt of the Gulf of Maine in winter), vertical mixings or upwellings freely follow the tidal circulation and the disturbing effects which the wind exercises on the surface; but if the superficial stratum be made much lighter than the underlying stata by freshening or by solar warming, it requires a considerable expenditure of force to drive the light surface water down or to bring heavy water up from below. It is conceivable, also, that the column might become so stable as to effectually insulate the deeps from any influence from above.

The activity of vertical circulation at any time or place in the gulf, therefore, depends on the momentary balance between the mixing tendency of the tides, etc., and the degree of vertical stability by which this is opposed.

It is important to bear in mind that any given particle of water has no stability *per se*, but only relative to the water above and below it. It is usual, therefore, in hydrodynamic calculations, to state the stability for strata of convenient thickness.[86] Being strictly a function of the density of the water, a simple visual measure of its relative value is afforded by the usual curves for density, plotted against depth, remembering that the more the curves depart from the vertical, the higher the stability, and that it is zero throughout any stratum where the curve is vertical.

Regional variations in this respect may be represented graphically by plotting the differences in density between the surface and some underlying stratum chosen as a base, as in Figure 185. The greater the difference, the the more stable the water.

In the Gulf of Maine the tidal currents are strong enough at all depths to effect an active mixing of the water, were they unhindered; and the consumption of slope water that takes place in the inner part of the basin (p. 941), with its constant replenishment from offshore, is unmistakable evidence of some interchange between surface and bottom. The prevalence of a decided contrast in salinity between the superficial and deep strata throughout the year proves this interchange a slow process, however, wherever the water is more than 100 meters or so deep. The limiting factor here is the stability of the water, for the specific gravity of the slope water in the bottom of the gulf is always considerably higher than that of the superficial stratum, even in winter, when the latter is heaviest and itself has little or no stability.

The gulf as a whole, then, is always in a state of stable equilibrium, whatever may be the state of the water near its surface; and while not sufficiently so to prevent vertical mixing from taking place constantly, we have no record of slope water welling up to the surface from the bottom of the trough, nor is such an event to be expected.

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[86] The unit of stability usually employed is the number of surfaces of equal specific volume per 10 meters of depth, represented graphically by vertical lines varying in breadth according to the stability of the water in the several strata. (Sandström, 1919, p. 283.)

The vertical stability varies little from season to season in the bottom stratum deeper than 100 meters, indicating comparative uniformity in the activity of vertical circulation there; but wide seasonal fluctuations in the stability of the superficial stratum reflect corresponding differences in the stirring effects of the tides, etc.

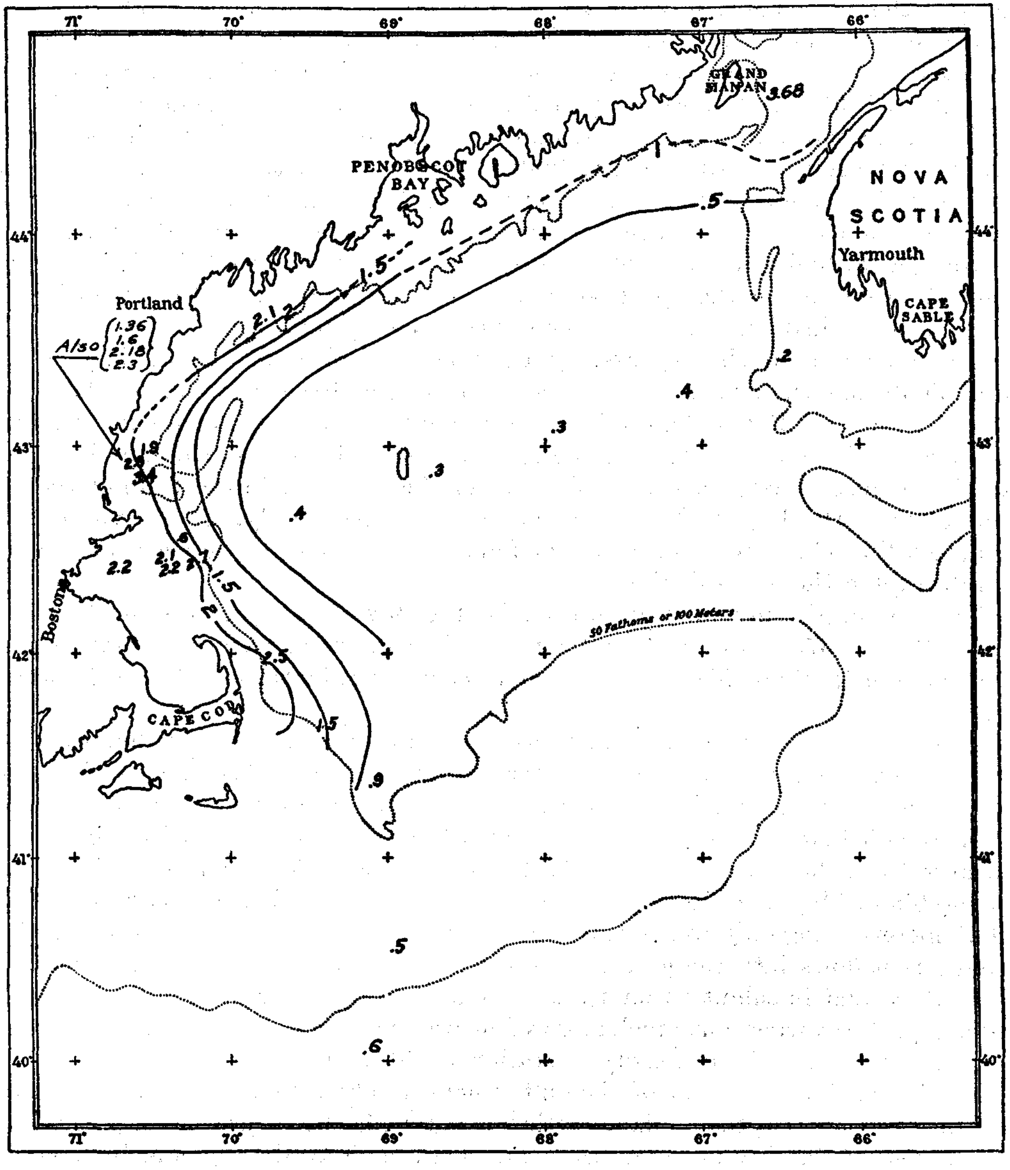

FIG. 185.—Difference in density between the surface and the 40-meter level for May, 1915 and 1920. Corrected for compression

In northern coastal waters generally (the Gulf of Maine is no exception) vertica mixing of the upper 100 meters is most active during the coldest season, when, thanks to low surface temperature, the water has little stability; and it is at this season that the consumption of slope water is most rapid. From March to April, however, vertical currents in the coastal belt between Cape Cod and Cape Ann are suddenly opposed by the increase in stability effected by the combined effect of the freshening of the surface by the river freshets and of the rising surface temperature. Together these processes produce an average difference of about 2 to 3.5 units of density between the surface and the 40-meter level in this zone by May (fig. 185). The most stable state yet recorded in the gulf was off the mouth of the Saco River on April 10, 1915 (Bigelow, 1914a, p. 417), when very low surface salinity (26.74 per mille) was responsible for a vertical range of 4.53 in density within this stratum, showing that vertical mixings had virtually ceased, for the time being. May also sees the rather sudden establishment of a high degree of stability in the Bay of Fundy consequent on the sudden lowering of the salinity of the surface by the freshets from the St. John River (p. 808), Mavor (1923) having recorded a difference of about 3.7 in density in the upper 40 meters on May 4, 1917, at *Prince* station 3, where the water had been virtually homogeneous on April 9.

The Penobscot freshet apparently has much less effect on the stability of the water off its mouth; and without sufficient inrush of fresh water along the coast between Penobscot Bay and Grand Manan to offset the active tidal mixing, we find that in May the upper stratum of the gulf is most stable in its two opposite sides, viz, Massachusetts Bay to Cape Elizabeth in the west and in the train of the St. John River in the Bay of Fundy in the east. Consequently, the active vertical circulation that characterizes the Bay of Fundy during most of the year is temporarily interrupted there at this time.

This period of temporary quiescence for the Bay of Fundy is of brief duration, Mavor (1923, p. 375) showing the 40-meter stability decreasing again by June to only about one-fourth of the May value as the river water is incorporated into the water of the bay.

I can not state the stability along western Nova Scotia for May; but it is not likely that the small amount of fresh water emptying in along this sector of the coast line can offset the active mixing which the strong tidal currents tend to effect there.

In the offshore parts of the gulf, to which the freshening effect of the increased discharge from the rivers has not yet extended, the superficial stratum is but little more stable in May than in April, the average difference in density between surface and 40 meters rising only to about 0.3 over the basin generally. The Nova Scotian current, as it flows into the gulf from the east, is so nearly homogeneous, both in temperature and in salinity, that it, too, is but slightly stable, though considerably lighter than the warmer but much more saline water in the eastern side of the trough over which it floats (cf. the density at station 10270, p. 988).

In the southwestern part of the gulf generally, where tidal currents are weaker than in the northeast, their mixing action is not sufficient to prevent a progressive development of stability in the upper 40 meters through April, May, and June as the surface warms; and as soon as the surface temperature has risen appreciably above that of the underlying water, upwellings are readily recognized by their chilling effect.

As remarked in another chapter (p. 550), water often wells up from below along the western side of the gulf in spring, when offshore gales drive the surface water out to sea. Bathers on New England beaches also are familiar with this same event in summer (p. 588). The fact that the surface averages somewhat cooler along the coast at that season, from Cape Cod to Cape Elizabeth, than a few miles offshore probably reflects the cumulative effect of such upwellings following the prevailing southwesterly winds. No doubt this happens still more frequently there in winter, when northwest gales are frequent, though it is not so easily recognizable then. In the opposite side of the gulf the tendency is the reverse—i. e., the surface water is driven in against the shore and sinks; and with vertical mixing by the tides so active that

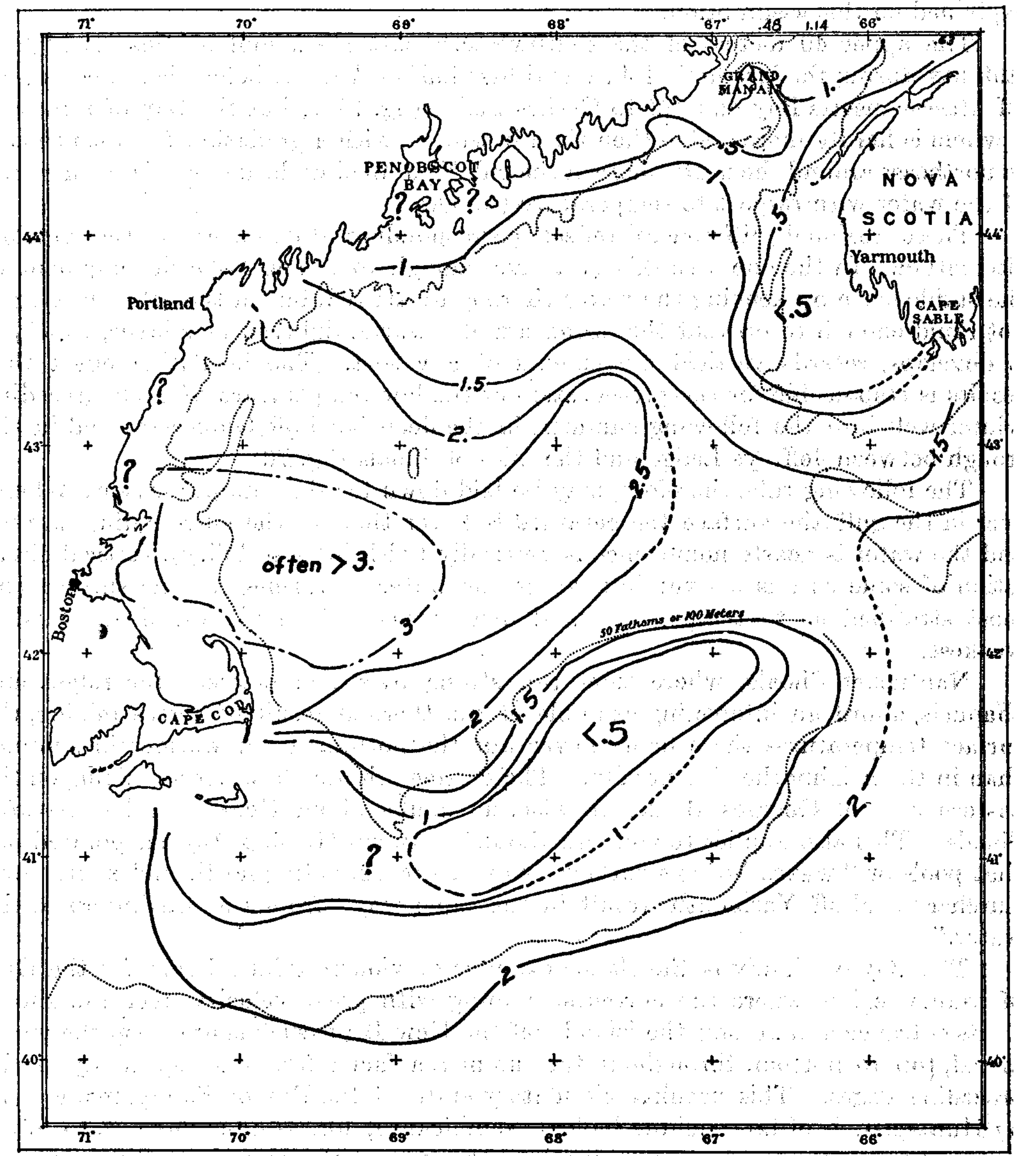

FIG. 186.—Difference in density between the surface and the 40-meter level in July and August for the several years of record, combined. Corrected for compression

but little stability develops there, more or less overturning of this sort probably takes place along the coast of Nova Scotia even at the warmest season. The frequency with which bottles have stranded there after drifting across the gulf may be explained on this assumption.

The upper 40 meters of the southwestern part of the gulf attains its highest stability during the last half of July and first half of August, being then most stable off Massachusetts Bay and out to Cashes Ledge (fig. 186); but the Bay of Fundy as a whole is hardly more stable then than in winter, with a gradation from southwest to northeast around the north shore of the gulf,[87] paralleling the degree of stratification of the water with respect to temperature (p. 596).

These regional differences reflect corresponding differences in the vertica circulation. In the one case this is active enough to prevent the development of the stable state by keeping the water thoroughly stirred, but in the other mixing is not rapid enough to prevent the formation of a warm, light, surface layer, which, as it develops, retards vertical movements of any sort. The insulating effect that results is responsible for the preservation of the low temperature of each preceding winter well into the following summer, in the deep bowl off Gloucester and in the trough between Jeffreys Ledge and the Isles of Shoals (fig. 70).

The following rule, therefore, may be laid down for the summer season: Whereever in the gulf the surface temperature is lower than in the surrounding waters, and the water is nearly homogeneous vertically (with little stability), vertical circulation of some sort is active; but where the water is warmest at the surface and most stratified as to temperature and density vertical circulation of any kind is weakest.

Nantucket Shoals, where tides run strong over and between the ridges and channels, afford an interesting example of the thermal result of active mixing, the surface temperatures there being lower but the bottom water warmer in summer than in the neighborhood generally. These same criteria show active mixing on the eastern side of Georges Bank; likewise, no doubt, about Georges and Cultivator Shoals. This also applies to German Bank. Dawson (1905, p. 15) has pointed out that pools or " wakes" of low surface temperature, extending north and south from Lurcher Shoal off Yarmouth, result in the same way "from the stirring up of the water."

The Bay of Fundy is the classic example of violent tidal stirring for the Gulf of Maine region, where the currents, running with great velocity over the shoals at its entrance and among the islands off the New Brunswick shore, keep the water mixed, top to bottom, throughout the summer, a fact referred to repeatedly in the preceding pages. This peculiar circulatory state of the Bay of Fundy, made clear by Huntsman, is of far-reaching biologic significance; for, as he points out, so low a surface temperature is thereby maintained throughout the summer that "conditions approximating those in the far North are produced in shallow water" (Huntsman, 1924, p. 281).

The rush of the tides between the islands along the coast of Maine, east of Penobscot Bay, is similarly reflected in low stability and slight thermal stratification (p. 599).

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[87] Only about one-third as stable near Mount Desert and one-tenth as stable near Grand Manan as at the mouth of Massachusetts Bay.

The courses of the curves for 1.5, 2, and 2.5 units of density on the chart (fig. 186) give evidence that the shoal ground off Penobscot Bay and out to Cashes Ledge also is the site of considerable vertical disturbance as the tidal currents are deflected by it.

As summer passes into autumn and the surface waters commence to cool, the parts of the gulf that are most stable in summer become less and less so, with little change in the eastern part, where the whole column of water loses heat more uniformly. The result is that vertical mixing is less and less opposed in the western part of the gulf and regional differences decrease in this respect.

The autumnal decrease in stability is illustrated for the southwestern part of the gulf, generally, by the offing of Cape Ann, where the upper 40 to 50 meters lose stability most rapidly during the early autumn, then more slowly but constantly through the winter. At depths greater than 100 meters no regular seasonal succession appears, all the curves being roughly parallel, their differences attributable to annual fluctuations in temperature and salinity. The seasonal succession is essentially of this same kind in the deep water in the northeastern corner of the gulf, though, thanks to strong tidal currents, the seasonal range of stability in the upper 40 meters (expressed in terms of density) is only about one-third as wide here as it is off Cape Ann.

Stability offers but little opposition to the free vertical circulation of water in any part of the gulf after November; less near the surface than at greater depths, as appears from the following table for October and November of 1916:

Vertical range in density for the superficial stratum and for the mid stratum

Station	0 to 40 meters	40 to 100 meters	Station	0 to 40 meters	40 to 100 meters
10399	0.79	1.00	10402	0.12	1.00
10400	.54	.90	10403	.55	1.30
10401	.51	1.35			

The free mixing that takes place from that time on throughout the winter is illustrated by the uniformity with which the upper 50 to 100 meters cool off during December, January, and the first half of February; evidently, water is constantly being brought up to the surface from below, there to radiate its heat, and water cooled at the surface is as constantly sinking.

It is not necessary to follow in detail the changes in stability that take place in winter in this connection. It is lowest over the gulf as a whole at the end of February or first of March, when the difference in density between the surface and the 40-meter level has been only 0.1 to 0.33 for all our stations on the banks and within the gulf, except at one off the Kennebec River (station 20058).

In fresh-water lakes, in high latitudes, autumnal cooling increases the density of the surface until a dynamic overturning of the water regularly follows. Our first winter's work in Massachusetts Bay (Bigelow, 1914a, p. 387) suggested that this same process was partly responsible for the rapid chilling that takes place there; but subsequent study, and especially the observations made in the bay from the *Fish Hawk* in 1925, proves this earlier interpretation erroneous and make it unlikely that dynamic overturning ever occurs in the open gulf, unless on a small scale and confined to a very thin superficial stratum. This statement is based on the fact that the density has been slightly lowest at the surface at all our winter stations, when compression is allowed for, though without this factor the surface stratum would often appear heaviest. It is true that the stability of the water is virtually *nil* in winter; but tidal stirring and the stirring effect of the wind are everywhere so active during the cold months that they more than keep pace with the chilling of the surface by constantly bringing up new water from below to take the place of the surface layer as the latter chills and before it is heavy enough to sink.

The thermal effect of mechanical mixing is essentially the same as that of dynamic overturning, however—i. e., to bring the whole column of water within the chilling influence of the low air temperatures. It is possible that dynamic overturning does occur locally in the coastal zone, but it has not actually been recorded there.

Vertical dynamic circulation of another sort was observed in Massachusetts Bay in February, 1925, where water, chilled at the surface close to the land, was moving offshore on the bottom, and with surface water from offshore moving in above it to take its place, as described above (p. 659). A more detailed survey of the temperature of the coastal belt in winter may show that circulation of this sort is more widespread than appears from observations taken so far.

DYNAMIC EVIDENCES OF CIRCULATION

CONSTRUCTION OF DYNAMIC CHARTS

Given a difference of pressure between any two stations in the sea, a current will result as surely as water will flow out through a dam when the sluice gate is opened, unless opposed by a stronger counterforce or an unpassable barrier. Even a preliminary examination of the dynamics of the gulf (and no more is attempted here) may be expected greatly to amplify such knowledge of its dominant circulation as has been gained from the more direct lines of evidence discussed in the preceding chapters.

The method of attack chosen here is that of the dynamic-contour chart, widely employed by European oceanographers and recently described by Smith (1926). For the sake of the nontechnical reader, an explanation of the principles involved in its construction and its interpretation are attempted here in the simplest possible language.[88]

In the sea, gravity, acting always directly downward, will set the water in motion if its surface slopes at all; and even if the surface of the water be level, currents will be caused if its specific gravity is greater at one place than at another, because the pressure exerted by the water at a given depth must then vary correspondingly, and the plane at which the pressure is uniform must be oblique to the pull of gravity. All this is embodied in the old adage, "water seeks its own level."

Although the physical principles that govern the gradient currents in the sea are simple, calculation of the drifts that will actually result from any given distribution of specific gravity is so complex that Bjerknes's (1898, 1910, and 1911) illumi-

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[88] See also Sandström (1919) for a simple explanation of hydrodynamic principles.

nating application of mathematical methods first offered a practical and easy method of solution.

Since that time European, and especially the Scandinavian, oceanographers have devoted much attention to the dynamic calculation of ocean currents, with such success that great advances in our knowledge of oceanic circulation are to be expected. Sandström (1919) has also studied the dynamics of Canadian Atlantic waters; Wüst (1924) of the straits of Florida and neighboring parts of the Atlantic; and Smith (1926, 1927) of the "Labrador" and "Gulf Stream" currents around the Grand Banks.

The simplest and most graphic method of learning the directions followed by the dynamic circulation in any sea area is by a horizontal projection showing (by contour lines) the regional variations in the thickness of the column of water included between the surface of the sea and the level at which some given pressure, equal for the whole area, is reached.

If the specific gravity[89] of the water is regionally uniform over the whole area, the depth of the layer so bounded will equally be uniform, and there will be no dynamic flow from any one part of the picture to any other; but if the weight of an equal thickness of water be greater (i. e., its specific gravity higher) at one locality than at another, a lesser thickness will produce a given pressure at the heavy station rather than at the light, and such a flow will tend to develop.

Consequently, calculation of the height of the column of water necessary to exert a given pressure for any two stations will give the dynamic tendency existing between them in the stratum included in the calculation; and if the survey can be extended to include a number of stations, scattered netlike over any part of the sea, we arrive at the dynamic gradients for the whole area.

This calculation is based on the principal that the pressure exerted by a column of water of unit area is the product of three arguments—its height, its specific gravity, and the acceleration of gravity; and if the first and the last of these be combined into dynamic units of measurements, as explained below (p. 932), pressure may be stated still more simply as equal to the height of the column (in dynamic units), multiplied by its specific gravity. Or, conversely, the height of the column (in dynamic units) will equal the pressure it exerts, multiplied by the reciprocal of the specific gravity of the water, namely, by its specific volume.

For example, if the specific gravity of a given column of water be 1.026, and it be desired to find the height or depth (in dynamic units) necessary to exert 50 units of pressure, we have: Specific volume $0.97466 \times 50 = 48.73300$ dynamic units of depth. If at a neighboring station the specific gravity is only 1.022, 48.92350 units of depth will be requisite to effect this same pressure, so that there will be a dynamic slope between the two stations of 0.2 dynamic units of height (or depth).

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[89] A brief definition of the much-abused term "density" as employed to express the specific gravity of sea water follows:

In hydrodynamic calculation what is important is the specific gravity that the water in question actually possessed at its temperature at the time and under the pressure to which it was actually subjected—i. e., *in situ;* not that which it might have possessed at any other temperature or depth.

The specific gravity of sea water differs from that of distilled water only in the second and subsequent decimal places. To avoid the use of such long decimal fractions it is usual to subtract 1 and to multiply by 1,000, substituting the term "density" for "specific gravity." For example, the density of sea water of a specific gravity of 1.025 is stated as 25.00.

Specific volume (merely the reciprocal of density) is the more convenient value to use in numerical calculation.

The practical application of this theorem to hydrographic problems thus hinges on the selection of suitable unit values for thickness and for pressure; the selection of such was not the least of Bjerknes's contributions to dynamic oceanography.

The force responsible for dynamic currents in the sea is that of gravity—not the capacity for work inherent in the water itself because of its mass. Consequently, the unit of height (or thickness) used in hydrodynamic calculations must not only stand in a linear relationship to the unit of pressure, but it must also be a direct measure of the potential force of gravity, which accelerates all falling bodies equally, irrespective of their mass. The gravity potential set free when a unit mass of water flows down a sloping surface is the product of two arguments—(1) the vertical difference in height and (2) the accelerating force of gravity. The latter being about 9.8 meters per second, the dynamic value of 1 meter of linear height must (in the meter-ton-second system) be stated as 9.8 units. Thus, gravity performs one unit of work in $\frac{1}{9.8}=0.102$ meters, so that one dynamic decimeter = 0.102 meters, or one dynamic meter = 1.02 common meters. For the reason just stated this relationship between dynamic and common linear measure is constant, no matter what the density of the water under study may be.

It is not practical to make direct instrumental measurement of the pressure below the surface of the sea; this can be deduced only from measurements of the temperature and salinity, and these must be taken at predetermined depths.

To calculate the thickness of a column of water that will exert any given pressure—say 100 units—the first step then is to establish the specific volume. This decreases in the sea with depth; consequently, to learn the mean specific volume it is necessary to determine the value not only for the top but also at the bottom of the column. If we could know before hand how deep it would be necessary to lower our instruments in order to do this—in other words, if the pressure unit of thickness could correspond to the ordinary linear measure—evidently the procedure would be vastly simplified. Strictly speaking, this is impossible because the linear value of this pressure unit *must* vary with the specific volume of the water. In practice, however, as Bjerknes and Sandström and Helland-Hansen (1903) have explained, this objection vanishes because the specific volume of the water varies only so very slightly with depth that the value will be given for the bottom of the chosen pressure column if the readings are taken within a few meters of it, whether shoaler or deeper.

Consequently, if a pressure unit can be found, which shall nearly (even if not quite) correspond to the ordinary linear measure, we can learn the specific volume where the pressure is, say, 100 units, simply by measuring the specific volume at a depth of 100 meters. The selection of such a unit we owe to Bjerknes, who proposed the "bar" to be equal to the pressure exerted by 10 dynamic meters (or 10.2 common meters) of fresh water, not under compression, and at the temperature of its maximum density. By the theorem stated on page 931, that pressure is the product of linear height, specific gravity, and acceleration of gravity, the "bar" will then equal 9.9 meters of salt water 35 per mille in salinity and 0° in temperature, so that a decibar is virtually 1 meter of sea water. For the reasons just stated, if the salinity and temperature be taken at any chosen number of meters below the surface this will give the specific volume where the pressure is that same number of decibars. Thus, if in the example given on page 931 we read dynamic meters instead of units of thickness, the corresponding units of pressure will be 50 decibars.

If the dynamic depth to which it is necessary to descend into the sea to reach a given pressure be greater at one station than at another (as is necessarily the case if the specific gravity of the water varies regionally), only two alternative states are possible: (1) If the surface of the water is level, the given isobaric surface (surface at which the pressure is equal) must slope; or (2), if this isobaric surface is level, the surface of the sea must slope. The resultant circulation will differ accordingly.

If the first alternative actually prevailed, the obliquity of the isobaric surfaces would increase with depth and the dynamic circulation would be most rapid at the bottoms of the deepest oceans. However, as Sandström (1919) and Smith (1926) both have emphasized, this is directly contrary to the truth, for the bottom waters of the ocean show only very slight regional variations in specific gravity and move only with inconceivable slowness. Consequently, when a dynamic gradient exists over any part of the sea it is the surface that slopes. It is of the greatest importance to keep this concept constantly in mind, because the conventional dynamic representations in profile show the surface as level, and hence are likely to prove misleading.

If, then, the isobaric plane chosen as the base for reference in our calculations lies so deep that it is level, or virtually so, calculation of the thickness of the column of water necessary to effect this pressure for a number of stations shows the actual contour or shape of the surface of the sea. Dynamic-contour charts of the deep oceans, such as have been constructed by Helland-Hansen and Nansen (1926) and by Smith (1926), are cases in point. In shoaler waters, however, where surfaces of equal specific gravity, and consequently the isobaric surfaces, are oblique right down to the bottom, the calculated dynamic slope of the surface of the sea will either exaggerate or minimize the true slope of the latter.

This is the case in the Gulf of Maine. Consequently, the dynamic charts offered here can be taken only as a rough approximation to the state actually prevailing.

The actual charting of the dynamic gradients in horizontal projection is hardly as simple as the foregoing résumé might suggest because of the necessity for intergrating the individual values for specific gravity at the levels of observation to arrive at the mean values for the included intervals; because, also, the specific gravities must be converted into specific volumes, and because the latter must be corrected for compression. The last two steps, however, are robbed of all difficulty by Hesselberg and Sverdrup's (1915) tables, as simplified by Smith (1926, p. 18, Tables 3 and 4). Smith (1926) has so fully explained the construction of the dynamic chart, as well as the principles involved, in a publication universally accessible, that only one aspect of the procedure needs further comment here, namely, the modifications necessary in studying an area so shoal and with stations differing so widely in depth that it is not possible to refer all the calculations to any one isobaric base plane. In this case it is necessary to calculate the gradient between pairs of adjacent stations, afterwards referring all to some one chosen station. Furthermore, if the specific volumes of the water at the two members of each pair of stations are not the same at the greatest depth reached at the shoaler, it is obvious that the intervening mass of bottom water deeper than that level must be in dynamic circulation;

hence, it must be taken into account in some way in calculating the dynamic slope at the surface.

Jacobsen and Jensen (1926) have very fully discussed this question in their dynamic study of the Faroe Channel, finding that in most cases this effect of the bottom water may be sufficiently allowed for by arbitrarily applying to the dynamic gradient between the two stations in question the product of the difference in specific volume between them at the deepest level of the shoaler station multiplied by half the difference in depth. If the station where the calculation shows the surface as highest also has the largest specific volume at the deepest level of the shoaler of the pair, the gradient is to be increased by the amount of this correction—decreased if the reverse obtains. If the difference in depth be greater than, say, 150 meters or so, no arbitrary correction of this sort can be relied upon, consequently the dynamic gradient can be stated only within very wide limits. The only cure is to establish the stations closer together on future cruises.

The dynamic-contour chart[90] closely resembles an ordinary weather map in its general appearance, and it is as easily interpreted in terms of the resultant circulation. Dynamically, the water tends to flow down the slopes from the parts of the picture where the surface stands high to those where it is low, and at right angles to the contour lines. Actually, however, this could happen only at the equator. Everywhere else the effect of the earth's rotation so deflects this motion that the stream lines come nearly to parallel the contour lines, which may then be taken as directly representing the current, just as the direction of the wind is roughly parallel to the isobars on the weather map.

In the open ocean, where tidal currents are weak, the contour lines may even approximate the tracts of the particles of water if approximately constant acceleration has been established. This, however, does not apply in a region such as the Gulf of Maine, where the tidal currents average much stronger than the dynamic tendencies. In this case the latter act only to give to the tidal flow a character more definitely rotary than would otherwise be the case, or to strengthen the one tide at the expense of the other. Here the dynamic-contour lines show only the general advance which the water tends to make good in its tidal oscillations to and fro.

Because in every case the datum plane for the calculation is necessarily the underlying water, not the solid bottom of the sea, the motion indicated by the chart is not absolute, but is only relative to that of the deepest stratum of water included in the picture. If this be motionless, the calculated drift represents the actual motion of the surface (or chosen level) relative to the coast line, but not otherwise.

In the Northern Hemisphere, where moving bodies are deflected to the right, the direction of flow, relative to the plane of reference,[91] is to be identified by the rule that the gradient current will constantly have the lightest water (i. e., the highest surface) on its right hand, the lowest surface on its left, as it veers cyclonically around the latter. If the surface drift be faster than the bottom drift, as is usually the case, this indicated direction of flow will also be the true direction, relative to the bottom; so, too, if bottom and surface drifts be parallel, whichever

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[90] Dynamic-contour charts may as easily be constructed for any desired depth below the surface of the sea, as described by Smith (1926).

[91] In the Gulf of Maine this is the bottom water between the pairs of adjacent stations.

is the stronger. But if the bottom current be the stronger, and both currents are opposite or diverge by a considerable angle (as may rarely be the case in shoal water, though perhaps never in deep), the method is made unreliable.

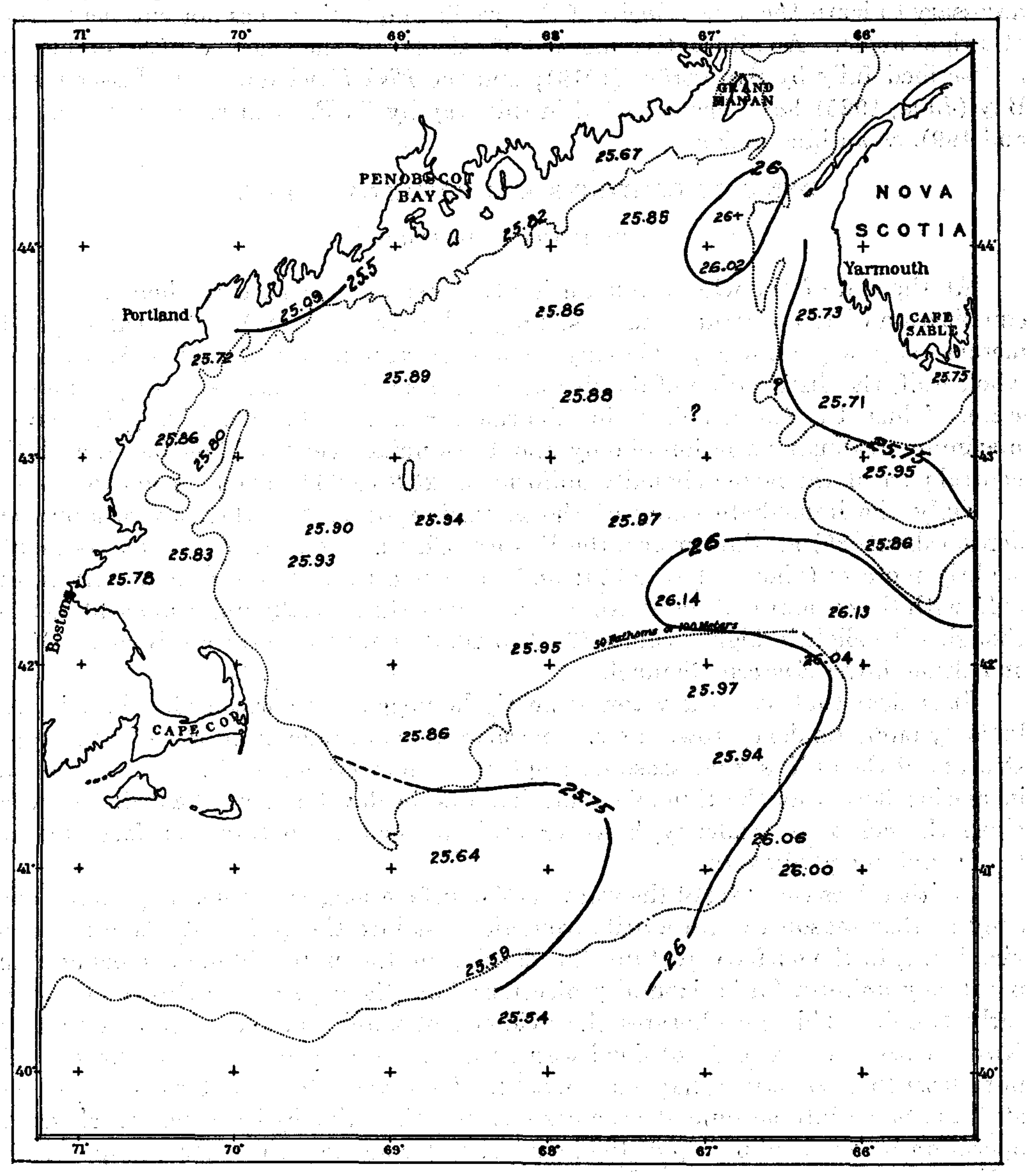

FIG. 187.—Distribution of density at the surface, February to March, 1920

In studying the dynamics of any shoal area it is also essential to appreciate the effect which the contour of the bottom may have in deflecting the gradient currents. This, of course, can not be stated by rule, but usually it is fairly simple of interpretation.

Once the dynamic gradient is established between any two stations, the corresponding velocity of the water at the one, relative to the other, is calculable by a simple formula, described by Smith (1926, p. 31), who also makes clear the correction necessary to learn the true velocity if the profile in question does not cut the current at a right angle. An alternative method of calculating the velocity, often employed, is described fully by Sandström (1919); and the *Fish Hawk* data for Massachusetts Bay (June, 1925) have been treated in this way by R. Parmenter (p. 949; figs. 198 and 199), as an illustration.

DYNAMIC CONTOURS AND GRADIENT CURRENTS

FEBRUARY AND MARCH

At the end of the winter and during the first days of spring, when the general equalization of temperature and of salinity (already discussed) makes the upper 40 meters extremely uniform, regionally as well as vertically (pp. 522, 703), over the whole gulf, the distribution of density at the surface would suggest a very quiescent state. Thus, the surface chart for February and March, 1920 (fig. 187), shows a maximum regional variation of only about 0.4 units over the whole basin, with the central part of the latter virtually uniform (at 25.8 to 25.9) from station to station.

Only the immediate offing of the Kennebec River was then appreciably less dense (about 25) at the surface, the Eastern Channel and the region off its mouth slightly more so (about 26 to 26.1); and the whole western and central part of the gulf, with the coastal belt along Nova Scotia, was then equally uniform at 40 meters, though with slightly higher values (26.3 to 26.5) along the eastern side of the basin and through the Eastern Channel.

It is clear that with the water so nearly homogeneous horizontally there is very little dynamic tendency toward any general system of gradient currents in the upper stratum of the gulf at that season, except that the freshening of the surface by the increasing flow from the Kennebec foreshadows the development of a drift westward along the coast—a tendency, however, still confined to so thin a surface stratum that it did not yet govern.

Neither does the state of the water at the surface suggest a general dynamic tendency at that season toward a drift from the east into the gulf past Cape Sable, or vice versa, in the surface stratum, the density of the upper 40 meters being comparatively uniform (in horizontal projection) from the cape out to Browns Bank for early March. This corroborates the evidence of salinity and temperature that the Nova Scotian current did not flood westward past the cape in the spring of 1920 until later than sometimes happens (p. 832). However, when the density of the deep strata is taken into account it becomes obvious that the hydrostatic forces set in operation by the banking up of the heaviest water against the eastern slope of the gulf (p. 849, fig. 172) must tend to cause a cyclonal or anticlockwise movement of the deeper mid strata, carrying with it, as an overlying blanket, the surface stratum, itself so nearly quiescent.

The dynamic chart for February and March, 1920 (fig. 188), gives an indication of the stream lines to be expected at the surface under the conditions of temperature and salinity then existing, which may be taken as typical of the first two weeks of spring. However, I must here caution the reader that at this time of year, when the propulsive force for gradient currents is derived mostly from the deep strata of

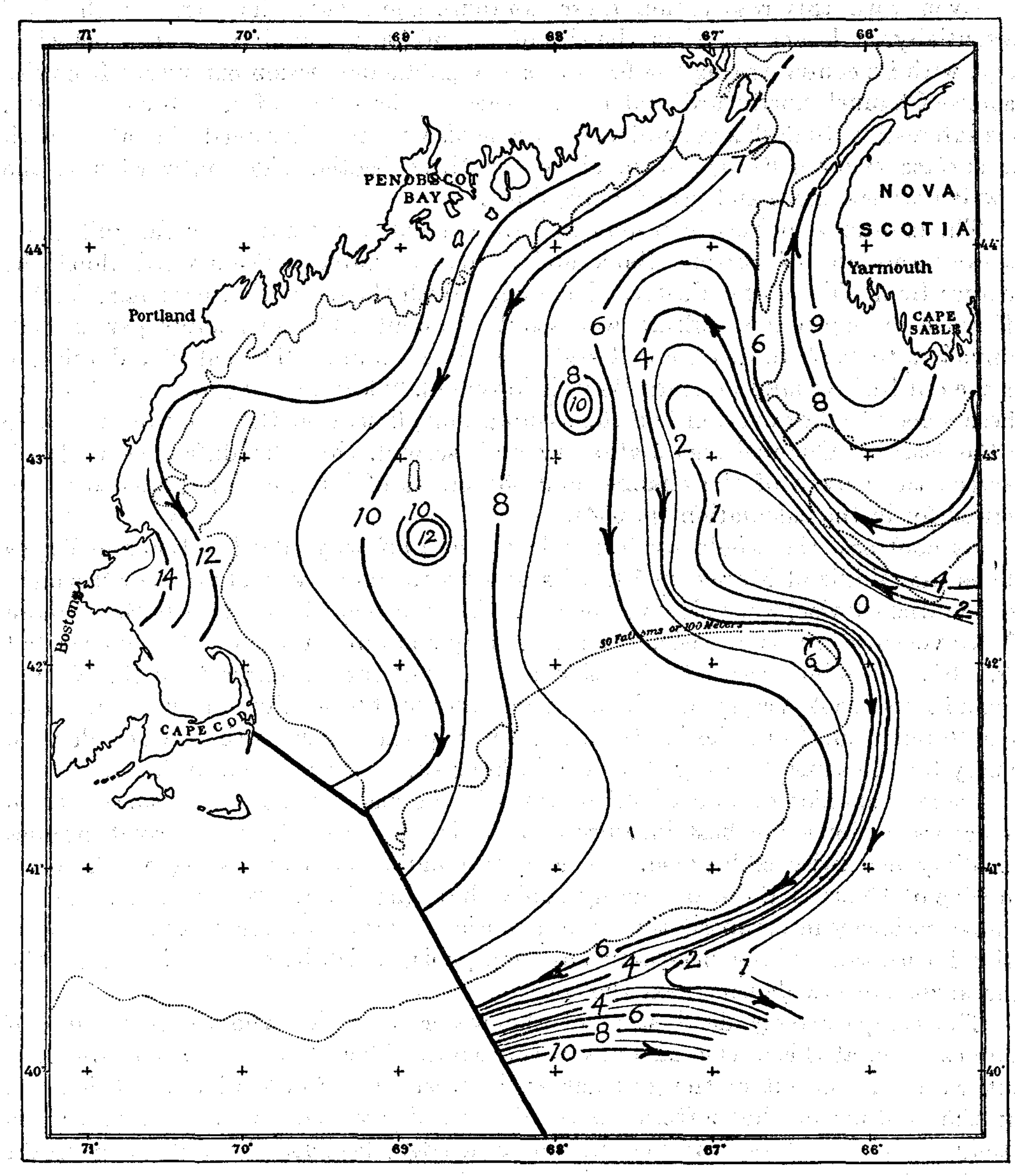

FIG. 188.—Dynamic gradient at the surface of the gulf for February to March, 1920, referred to the Eastern Channel as the base station. The dynamic heights are given for every dynamic centimeter. For further explanation see p. 937

water, the probable error introduced into the calculations by the necessity for assuming an arbitrary correction for the differences in depth between pairs of adjacent stations (p. 934) is relatively greater than for late spring or summer, when the surface stratum is moving more rapidly than the underlying water. Consequently, the contour lines on the early spring chart (fig. 188) and the dynamic gradients which they show can be accepted only as a rough approximation, not in detail. Some smoothing of the curves has proved necessary in the construction of the chart, also.

Even with this reservation these contours show that the basin of the gulf (potentially, at least) was then the site of one major cyclonal (i. e., anticlockwise) eddy, with its center taking the form of a troughlike depression extending from the Eastern Channel northward and inward toward the offing of the Bay of Fundy. It is interesting that this general eddy seems also to have involved the latter, with the surface water drifting inward along the Nova Scotian side, outward next the New Brunswick shore and past Grand Manan.

The highest velocities then indicated were a drift northward into the gulf along the western slope of Browns Bank and a counter movement outward along the Georges Bank side of the Eastern Channel. With the correction used here for the difference in depth this indraft works out at about 13.5 centimeters per second, equivalent to 0.27 knot, or about 6½ miles in 24 hours. The calculated velocity for the outdraft around Georges Bank is lower—0.22 knot, or 5¼ miles in 24 hours. These velocities, however, are on the assumptions, first, that the water in the center of the Eastern Channel was stationary and, second, that the difference in depth between the trough of the channel and the crests of its two slopes was correctly allowed for in the calculation (p. 934).

By contrast, the whole western side of the gulf was "dead," dynamically, as late as the middle of March, in 1920, its upper stratum only tending to drift southward (anticlockwise) very slowly, except at the mouth of Massachusetts Bay, where greater velocity in this direction is suggested by contour lines more closely crowded (fig. 188). It is interesting to find that the effect of the discharge from the Kennebec and Penobscot was most evident in speeding up the southwesterly surface drift some 40 miles out from the land—not close in to the latter, as the surface chart of density for the same date (fig. 187) would have suggested if taken by itself.

Lower densities at two of the stations in the basin (20054 and 20052) than in the general vicinity are best interpreted as isolated pools, which, if correct, implies sudsidiary clockwise eddies; so, too, a corresponding high appearing on the eastern edge of Georges Bank on the dynamic chart (fig. 188). While these seem not to have seriously interrupted the general anticlockwise movement, they are interesting illustrations of the persistence of such pools, which have drifted off from the general zone of low density next the coast.

The comparatively dead state of the water over the whole eastern half of Georges Bank at this season also deserves a word. The chart suggests a slow drift southward and so out of the gulf across the western half of the bank at this time, but the contour of the bottom makes it more likely that the surface water was actually moving eastward around its northern edge, because the underlying strata (which in this case supplied the motive power) are necessarily directed by the submarine slope, against which any southward drift must strike. Thus, we may conclude that the dynamic movement of water around the basin was even more definitely eddylike and anticlockwise in March than the chart (fig. 188) suggests.

Lacking March data for the region of Nantucket Shoals, the chart fails to show whether a definite dynamic outflow is to be expected around the latter to the westward from the gulf at that season.

In the offing of Cape Sable the dynamic gradient for March,1920, calls for a weak drift clockwise but spreading far offshore toward Browns Bank before eddying northward again toward the gulf. Hence, thecold Nova Scotian water that we encountered midway out over the shelf (station 20075, p. 1000) did not then tend to round the cape, but to veer offshore, which agrees with the distribution of temperature and salinity at the time. Dynamic evidence also is strong that whatever water was then entering the eastern side of the gulf in the upper stratum was drawn chiefly from the region of Browns Bank and from the edge of the continent in the offing of Cape Sable—i. e., from the source whence the gulf regularly receives its slope water (p. 848).

The dynamic gradients for March are especially instructive along the continental slope abreast of the gulf because of the light they may throw on the problem of the so-called "Gulf Stream" along this sector. Fortunately, this is made comparatively clear for this region (fig. 188) by the considerable difference in density between the outer stations on the two cross profiles of the bank—western and eastern (stations 20044 and 20069). On the eastern profile the gradient (dipping to a low at the outermost station) shows a strong drift to the westward along the edge of the bank, its calculated velocity being about 0.6 knot, or 14 miles in 24 hours. While this calculation depends on the correct allowance for the difference in depth between stations, one of which was much deeper than the other,[92] the direction of this gradient current is well established. A weak continuation of this westerly drift (indicated by a low in the dynamic contour) extended along the edge of the bank as far as the western profile (run three weeks earlier); but here this gave place to a much steeper counter gradient to high in the next 10 miles offshore, implying a counter drift to the east.

Unfortunately, the difference in depth between the stations on the edge of the bank and outside is again so great on this profile (150 to 200 and 1,000 meters) that the arbitrary correction employed to take account of it becomes only a rough approximation, though the order of this correction (i. e., whether increasing, decreasing, or even tending to reverse the gradient calculated for equal depths) is in every case clear enough (p. 934). When all reasonable allowance is made for this source of error, however, the velocity of the easterly drift may safely be set as at least half a knot. Fortunately, calculation of the dynamic head between the two outermost stations on these two profiles is not subject to this error, both being deep enough (1,000 meters) to reach equal density at the lowest levels. Consequently the general contour, as laid down for this region in Figure 188, is established, as is the fact that the western profile reached out to water of comparatively high temperature and salinity in the upper stratum, while the eastern profile did not, though its outermost station was still farther out from the edge of the continent.

So long as the dynamic gradient continues to be of this sort it is evident that the superficial drift of warm water along the continental slope, commonly spoken of as the "inner edge of the Gulf Stream," is not only to be described as a typical gradient current but is to be expected within 15 to 20 miles of the edge of the bank between longitudes 68° and 69°. Farther east, however, the contour lines on the chart (fig. 188) show it departing farther and farther from the bank, agreeing in this

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[92] Station 20068, 200 meters; station 20069, 1,000 meters.

with general report. On the other hand, the westerly counterdrift set in motion along the inshore side of the dynamic depression (or cabelling zone) loses in velocity and hugs the bank more closely from east to west.

From the general oceanographic standpoint this demonstration that this sector of the "Gulf Stream" receives a propulsive impulse from the local hydrostatic forces (i. e., is strictly a dynamic drift) is one of the most interesting results of our explorations.

The upper 50 meters or so of the gulf being close to quiescent, dynamically, during February and March, the chart for the surface (fig. 188) will as well represent the gradient currents down to as deep as 100 meters or so for that season, leading to the interesting result that the whole column down to this depth tended to drift inward along the eastern side of the Eastern Channel at the time, outward along its western side, which is also evident in the profile (fig. 189). However, if we descend to as great a depth as 150 meters a rather different dynamic distribution appears, with the center of anticlockwise revolution located as a low close to the northern slope of Georges Bank, with a weak but definite tendency toward a gradient drift crossing the basin from northeast to southwest, shown better graphically by the dynamic contours (fig. 190) than verbally. This drift was then bounded on the west by a considerable dead area covering the whole west-central part of the basin (except as interrupted by a subsidiary high marking a clockwise whirl in the offing of Penobscot Bay), with a very weak southerly tendency along the western slope in the offing of Massachusetts Bay.

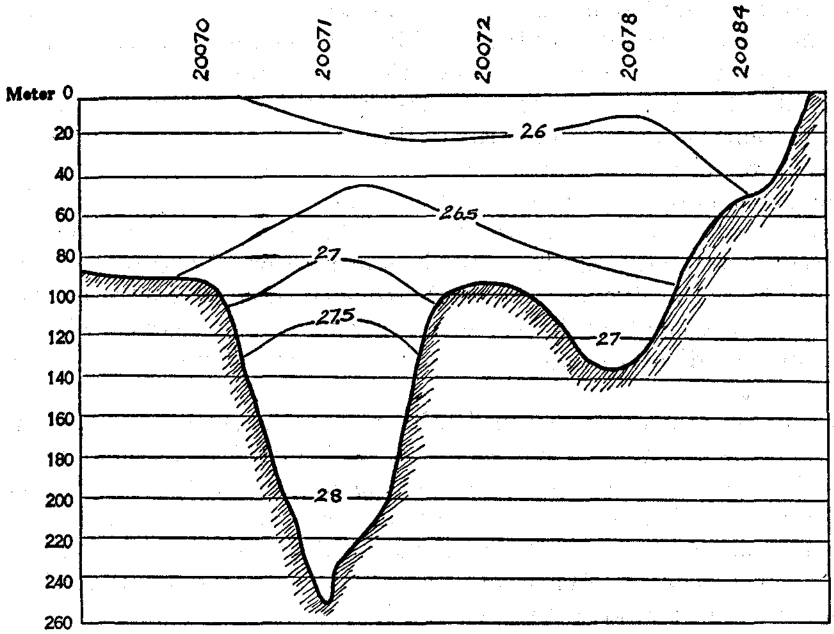

FIG. 189.—Distribution of density on a profile running from the eastern end of Georges Bank across the Eastern Channel, Browns Bank, and the Northern Channel, to the vicinity of Cape Sable, March 13 to 23, 1920. Corrected for compression.

In the eastern side of the area this deep projection points to a slow creep inward through the Eastern Channel; but with only one station in the latter it is impossible to state whether this creep involved the whole breadth at this depth or (which seems more likely) hugged its Browns Bank slope, as in the shoaler strata.

In interpreting the dynamic contours in terms of potential drift at a depth at which the basin of the gulf is entirely inclosed except for one narrow channel, it is obvious that prime consideration must be given to the contour of the bottom, as this controls the possible movement of the water. When this is taken into account, the March chart (fig. 190) affords the best clue yet available to the movement of the slope water over the floor of the gulf at a season when this is entering in large volume via the trough of the Eastern Channel (p. 850). Dynamic contours for the 150-decibar level, like the distribution of temperature and of salinity, show this indraft following the eastern side of the basin inward, to eddy westward and so southward; but instead of completing a circuit around the cyclonic center ("low" on the chart—fig. 190), the drift will obviously be deflected by the slope of Georges Bank. The angle at which the contour (or stream) lines strike the latter suggests an overflow into the dead western side of the basin. It is here, then, as well as along the northern slopes of the gulf, that the consumption of this slope water chiefly takes place during the early spring, as tides and wind currents constantly mix it with the less saline but colder stratum above.

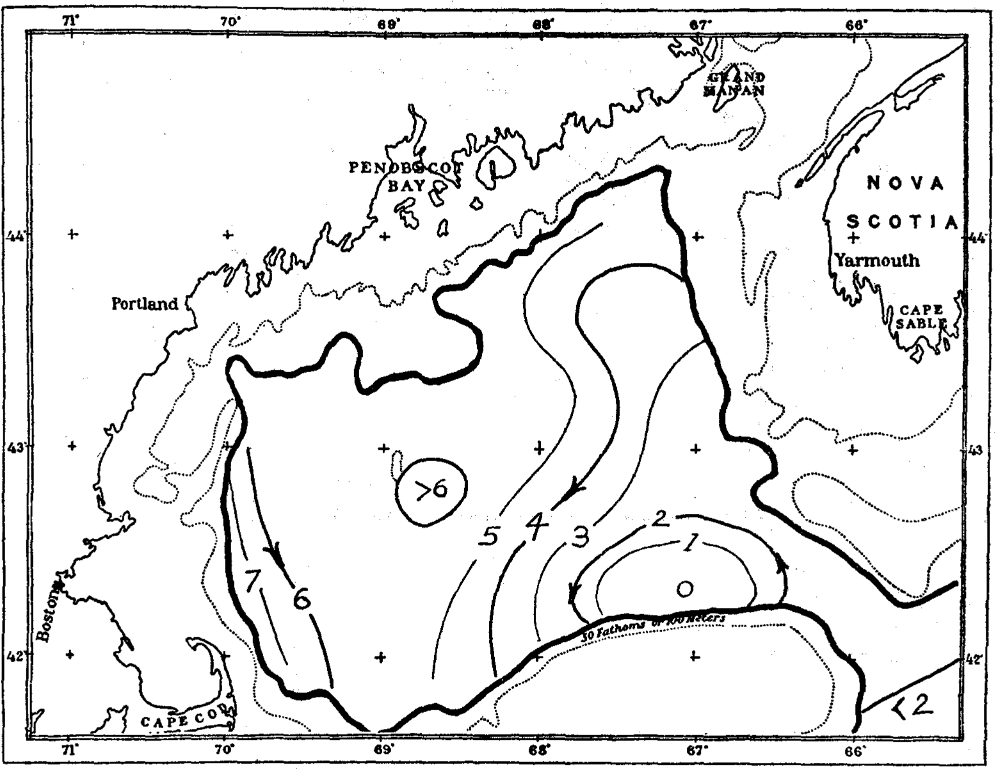

FIG. 190.—Dynamic gradient, bottom to 150 decibars, referred to the southeastern side of the gulf as base station, for February and March, 1920. Contour lines for every dynamic centimeter

The implication of a dynamic contour of this sort in the deeps of the gulf, combined with the effect of the confining slopes and with this consumption in the inner part, is obvious; it provides a propulsive force to pump into the gulf the slope water with which the offing of the Eastern Channel is kept supplied—also dynamically—from the source of manufacture to the eastward (p. 847).

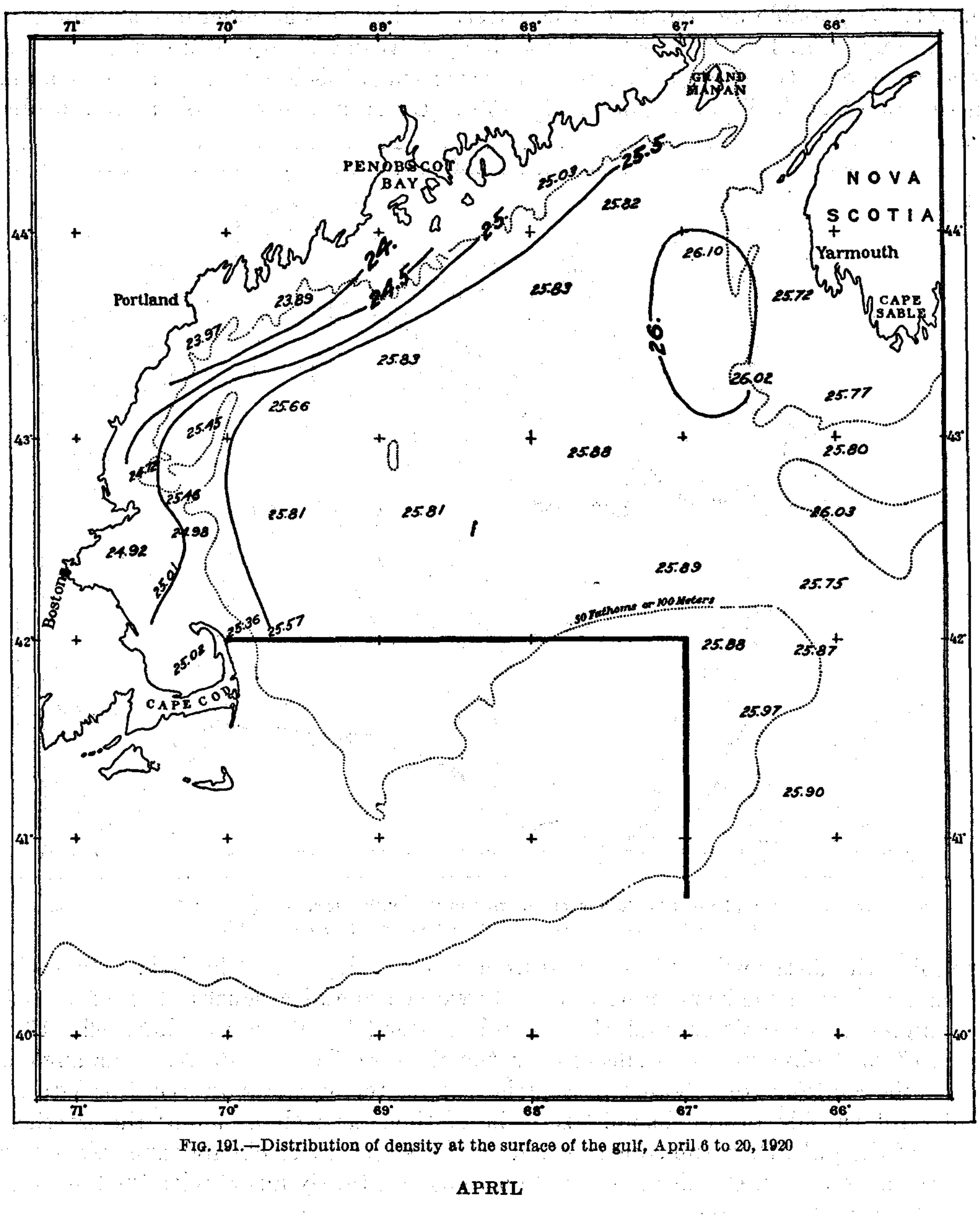

FIG. 191.—Distribution of density at the surface of the gulf, April 6 to 20, 1920

APRIL

The progressive freshening of the surface, which takes place along the northern and western shores of the gulf with the advance of spring, results in the development of a corresponding coastwise belt of low-surface density by April, grading abruptly to considerably higher values a few miles out in the basin (fig. 191). This development adds both velocity and volume to the longshore drift west and south, which was foreshadowed on the March chart (fig. 188).

In 1920, according to the dynamic contours at the surface (fig. 192), this spring current had come to dominate the entire coastal belt of the gulf from the neighborhood of Mount Desert Island (probably from the Grand Manan Channel) to Cape Cod by the middle of April, and probably it does so every year by this date—earlier in years when vernal progression in the sea is more forward. During the period covered by this April cruise the average calculated rate of this current, referred to the "low" in the offing of the Bay of Fundy (assumed stationary), was about 0.3 knot abreast of Mount Desert, about 0.18 knot abreast of Cape Cod, or an average drift of about 5¾ miles per 24 hours along this coast sector as a whole. In spite of the sources of unavoidable error this calculation falls at least within the order of magnitudes suggested by other lines of evidence.

In Massachusetts Bay, also, a continuation of this longshore drift is indicated by the dynamic contours from the north shore around toward Cape Cod. This, again, agrees with the drifts of bottles that were set out a few miles north of Cape Ann in April, 1925 (p. 890; fig. 177); and evidently this is the characteristic state during that month, for salinities and temperatures taken in the bay by the *Fish Hawk* on April 21 to 23, 1925, show a drift of low density (fig. 193) southward past Cape Ann and across the mouth of the bay to Cape Cod as the water from the Merrimac and other rivers to the north floods southward.

Surface projection (fig. 191) and dynamic contours (fig. 192) for April unite in locating the low in the offing of the Bay of Fundy some 60 miles off Mount Desert Island for that month, the whole east-central part of the basin out through the Eastern Channel being virtually dead dynamically, contrasting with a weak northerly set along the western shores of Nova Scotia. In the southern side of the area the dynamic contours point to a persistence of the drift out of the gulf to the south around the eastern end of Georges Bank, just described for March (p. 938; fig. 188), though at a lower velocity; but as a result of the equalization of temperature and salinity from the Eastern Channel in across Browns Bank (p. 553) only a very slow movement into the gulf along this side of the channel is suggested by the April chart (fig. 192).

The general result of the lightening of the northern and western margins of the gulf, combined with the shift of the cyclonal low northward across the basin, which follows a slackening in the indraft of slope water, is to give the anticlockwise circulation more definitely the character of a great eddy in April than in March, centering off the Bay of Fundy and with its western side traveling southward with greater velocity than its eastern side drifts north.

It is probable that in April the gradient currents are given an easterly direction along the northern slopes of Georges Bank, just as in March (p. 938), by the contour of the bottom, with a separation off Cape Cod between this easterly drift and a southerly drift past the cape and past Nantucket Shoals. This suggestion is corroborated by the fact that bottles followed both these routes from Massachusetts and Ipswich Bays in April, 1925.

MAY

Progressive incorporation of river water into the northern and western sides of the gulf, coupled with vernal warming, constantly favors the anticlockwise movement of the so-called "spring current" (fig. 194); and with the resultant changes in salinity and temperature affecting chiefly the surface, the site of the chief dynamic impulse toward circulation shifts from the deep strata to the superficial. In May, 1915, for example, a difference of about 1.5 units of density was recorded at the surface between the vicinity of the mouth of Massachusetts Bay and the basin in its offing (fig. 194) in a distance of 30-odd miles, but only about one-seventh as wide a difference at the 50 or 100 meter levels (stations 10266 and 10267).

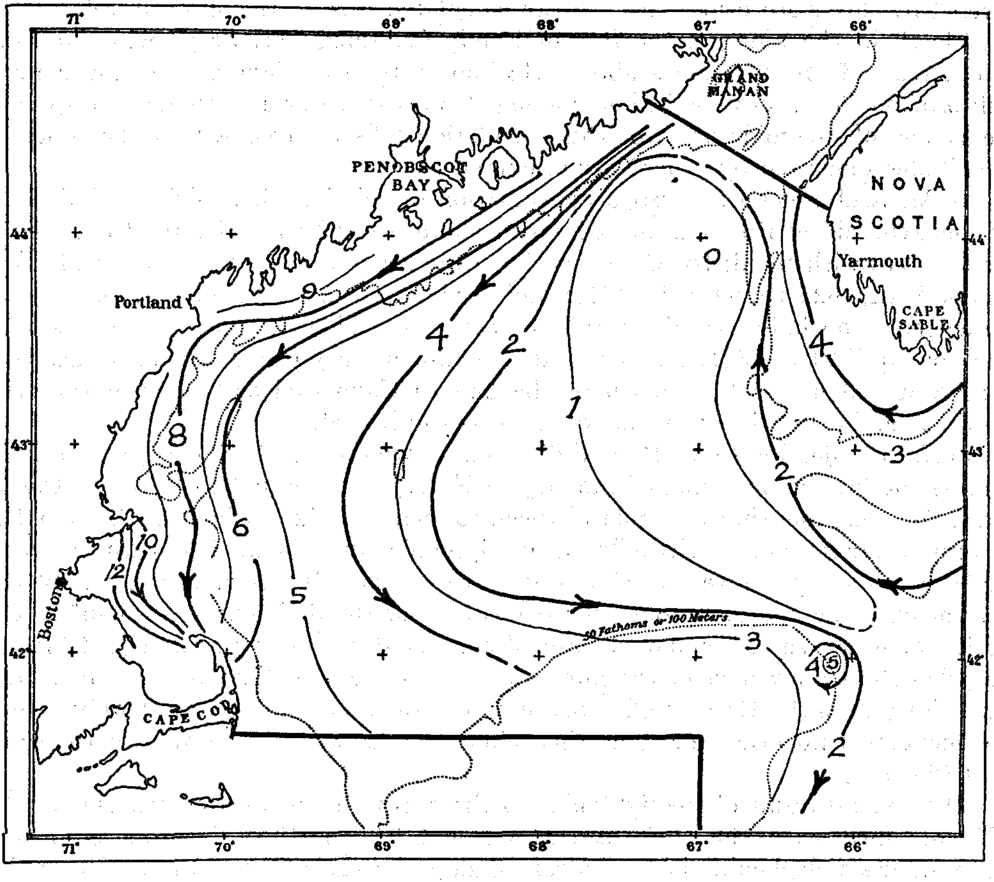

FIG. 192.—Dynamic gradient at the surface of the gulf, April 6 to 20, 1920, referred to the offing of the Bay of Fundy as base station. Contours for every dynamic centimeter

As a result, the dynamic chart for May (fig. 195) corresponds closely to the distribution of density at the surface, except for the relationship between the shallows of German Bank and the deep water immediately to the west of the latter. In this region the surface projection, taken by itself, would give a false picture, being confused by the strong tides that keep the water thoroughly stirred over the bank, thus

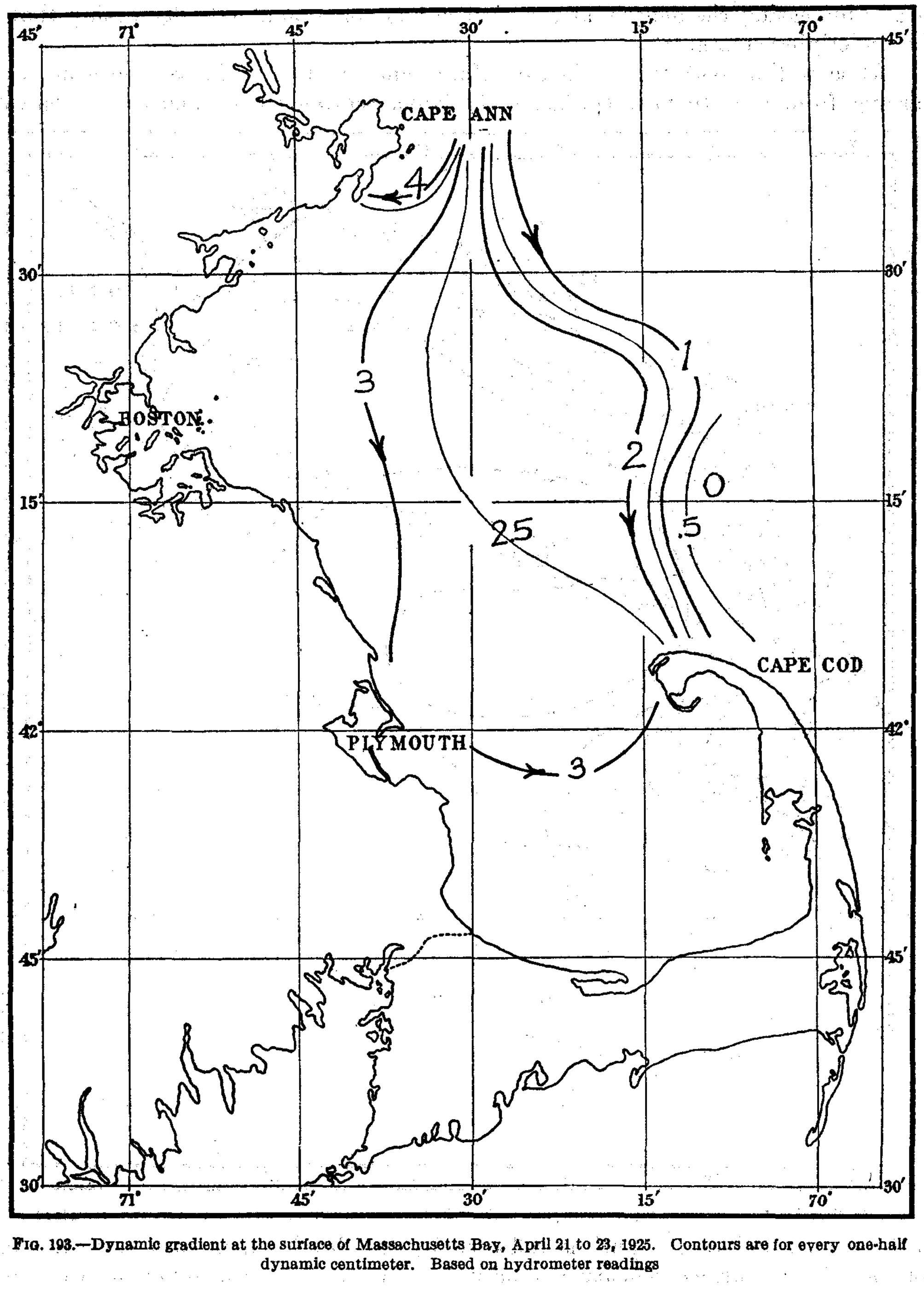

FIG. 193.—Dynamic gradient at the surface of Massachusetts Bay, April 21 to 23, 1925. Contours are for every one-half dynamic centimeter. Based on hydrometer readings

locally increasing the density at the surface but correspondingly decreasing that of the underlying strata.

At some time between the last of March and the first of May—the exact date varying from year to year (p. 832)—the Nova Scotian current, flooding westward past Cape Sable into the gulf, is reflected by the development of a corresponding tongue of low surface density extending westward from the offing of the cape. Thus, in 1919 the eastern half of the Cape Sable-Cape Cod profile proved less dense than the western in the upper 50 meters at the end of March and again at the end

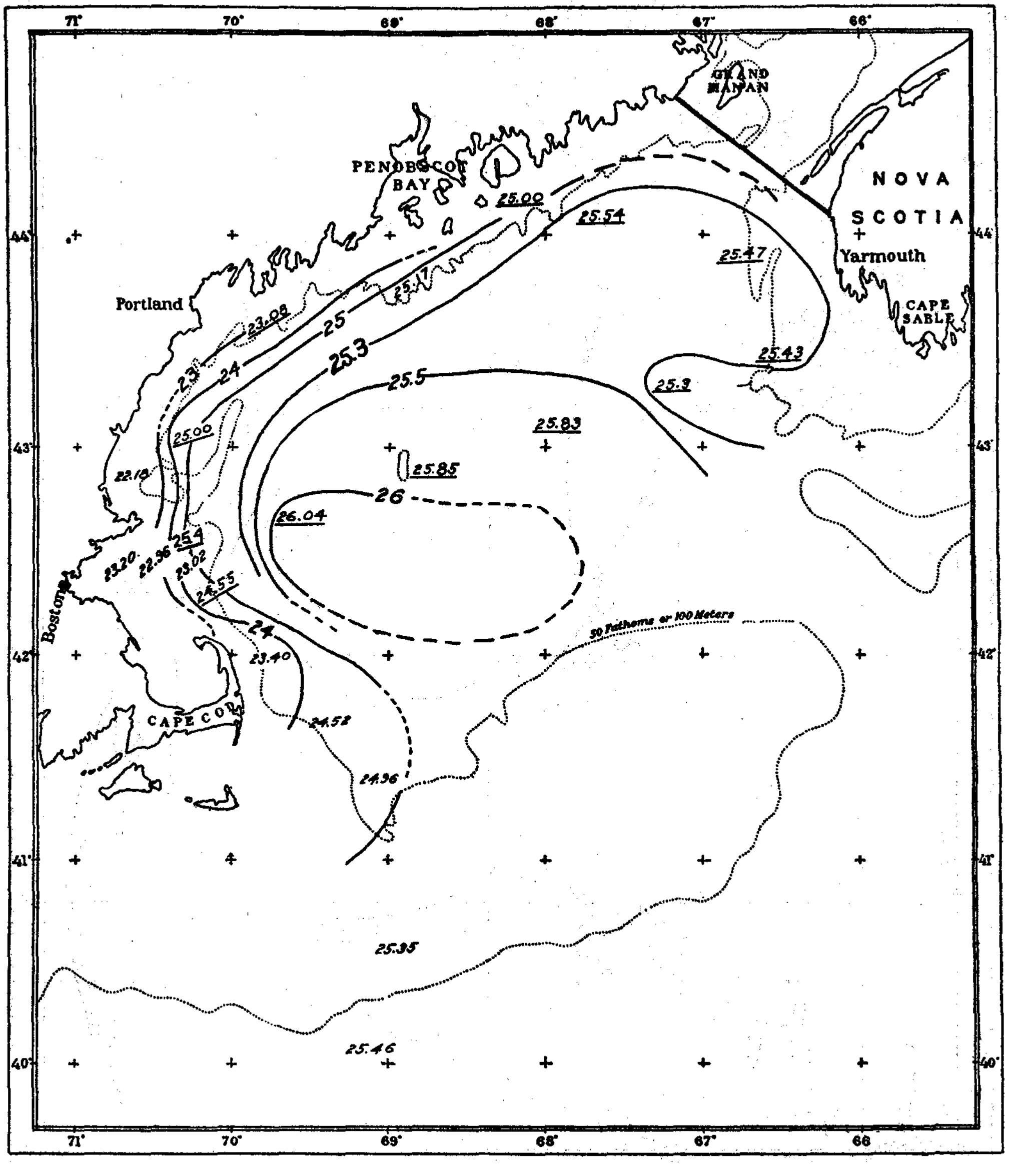

FIG. 194.—Distribution of density at the surface of the gulf or May, 1915 (underlined), and May, 1920, combined

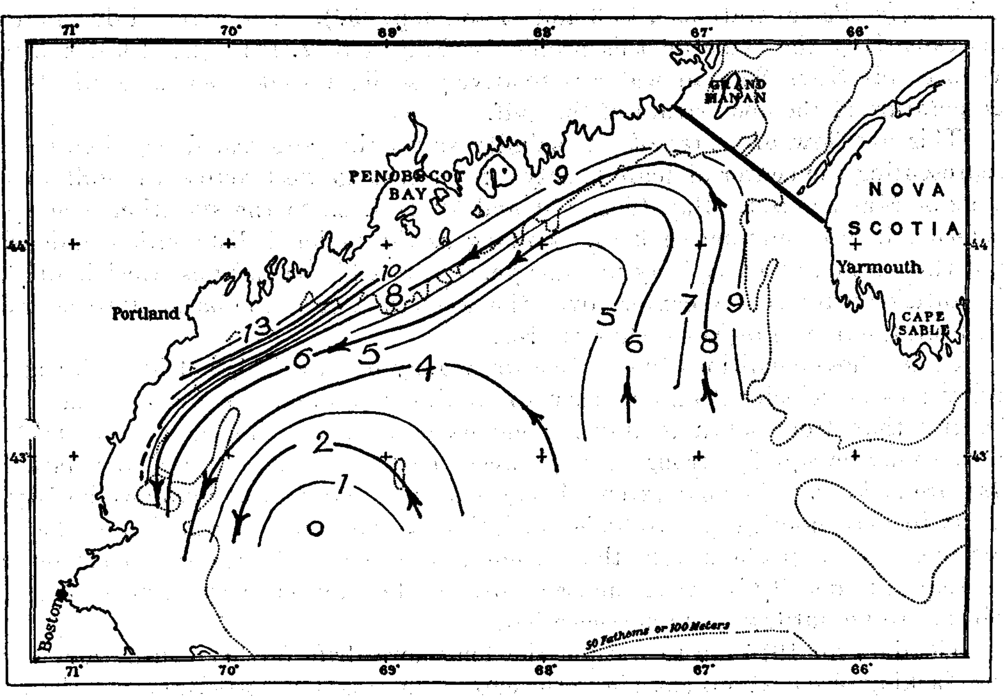

FIG. 195.—Dynamic gradient at the surface, for the northern part of the gulf, May 4 to 14, 1915, referred to the offing of Cape Ann as base station. Contour lines are for every dynamic centimeter

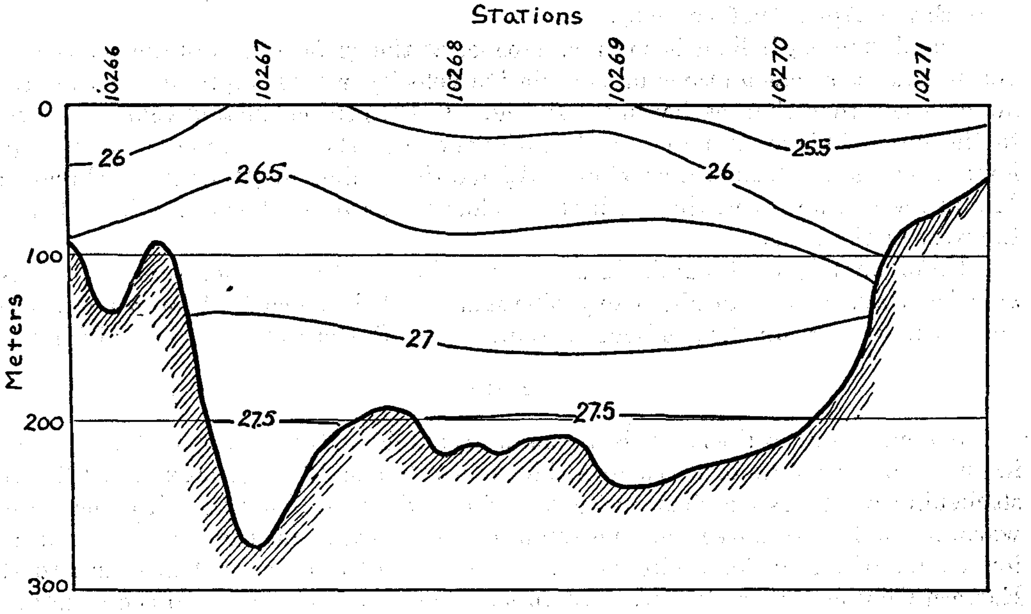

FIG. 196.—Density on a profile crossing the gulf from Massachusetts Bay toward Cape Sable, May 4 to 14, 1915. Corrected for compression

of April (Ice Patrol stations 2 to 3 and 21 to 23, p. 997). The regional distribution was essentially the same on this profile for May 4 to 7, 1915 (fig. 196), and it is because this Nova Scotian water is relatively so light that it so little affects the temperature of the deep strata of the gulf.

This overflow of water of low salinity shifts the potential depression, or low (representing the center of high density), from east to west across the gulf to the offing of Massachusetts Bay (figs. 194 and 195)—i. e., to the situation where the surface is high in summer (p. 956). So long as the regional distribution of density is of this sort (from early May in some years; probably as early as April in others) the anticlockwise vortex centers over the western arm of the basin 30 to 50 miles out from the mouth of Massachusetts Bay.

Under these conditions the surface water may be expected to drift with considerably greater velocity from northeast to southwest around the western margin of the gulf than from south to north along its eastern trough (fig. 195), though the current may be equally strong next the west coast of Nova Scotia, where data for May are lacking. To what extent this anticlockwise circulation involves the Bay of Fundy in that month is yet to be learned, though the sudden freshening of the surface there by the freshets from the St. John River (p. 808) suggests a considerable differential in density between the two sides of the bay as characteristic of May, pointing to an outflow in its northern half.

The data for 1915 fail to outline the longshore drift farther south than Cape Ann, lacking observations close in to the cape or in Massachusetts Bay, but the very low densities recorded at the mouth of the bay in May, 1920 (fig. 194), show it continuing down past Cape Cod, consistent with the drifts of bottles set out in Massachusetts Bay in April, 1926 (p. 893).

The dynamic gradient is so much steeper at the surface than in the deeps of the gulf in May that calculations of the relative velocity would approximate the truth more closely then than earlier in the spring. In 1915 the calculated velocity relative to the low off Cape Ann (assumed stationary, fig. 195) was about 0.23 knot per hour near Cape Elizabeth, or about 5½ nautical miles in 24 hours. Abreast of Mount Desert, however, the calculated velocity was only about 0.14 knot toward the west at the time.

Unfortunately no dynamic data are available for the southeastern part of the area for May, so that nothing can yet be said about the effect that the Nova Scotian current may exert on the gradient currents of the Eastern Channel and vicinity.

JUNE

No one of our cruises affords a general dynamic picture of the gulf as a whole in June, but the state of its eastern side shows that in 1915, at least (fig. 197), the slackening of the Nova Scotian current from the east, coupled with the vernal warming and progressive incorporation of land water in the west, caused the low center of anticyclonic circulation to shift from the offing of Cape Ann to the Eastern Channel by the last week of June. This seasonal return to the location it occupies in March (judging from 1920) probably represents the normal progression, the physical changes on which it depends being yearly events.

With this gradient a considerable indraft is indicated into the eastern side of the gulf; not, however, from the coastal belt to the eastward of Cape Sable, but from the region of Browns Bank and of its offing. Probably this indraft had as a counter current an outdraft from the gulf around the eastern end of Georges Bank, though, lacking a station on the bank, this can not be asserted definitely. It is certain, also, that the dynamic impulse for a northeast-southwest current around the northern and western margins of the gulf had slackened by the middle of that June.

Unfortunately, no observations were taken in the western side of the gulf that June, but a survey of Massachusetts Bay carried out by the *Fish Hawk* on June 16 and 17, 1925 (cruise 14), has enabled Mr. Parmenter to calculate the relative velocities and directions of the gradient current on various profiles by the method elaborated by Sandström (1919), and his results are offered here to illustrate this alternative procedure.

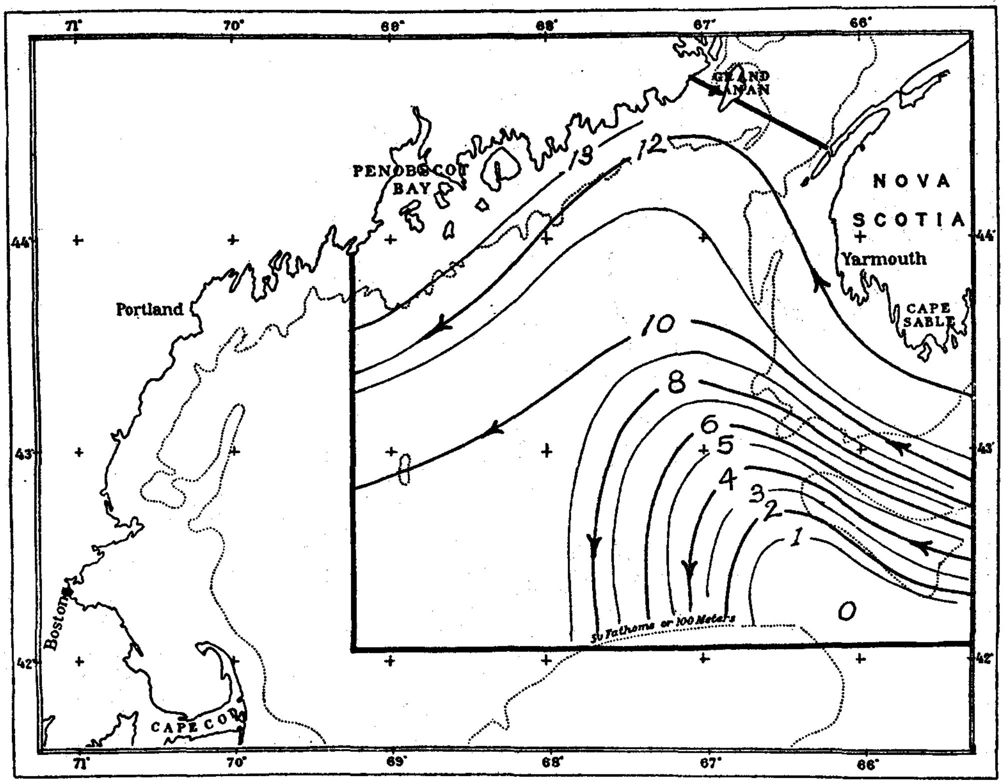

FIG. 197.—Dynamic gradient at the surface of the eastern side of the gulf, from June 10 to 26, 1915, referred to the Eastern Channel as base station. Curves are for every dynamic centimeter

These calculations (tabulated below) rest on two assumptions—first, that the water was stationary at the greatest depth of the shoaler of each pair of stations, and, second, that the profiles selected (typical examples are shown in fig. 198) are at right angles to the existing current. In the present instance neither of these requirements is exactly fulfilled, but the close agreement between the calculation and the general distribution of density in the upper 20 meters (fig. 199) makes it probable that the calculated directions are a close approximation to the actual dynamic tendency toward circulation at the time.

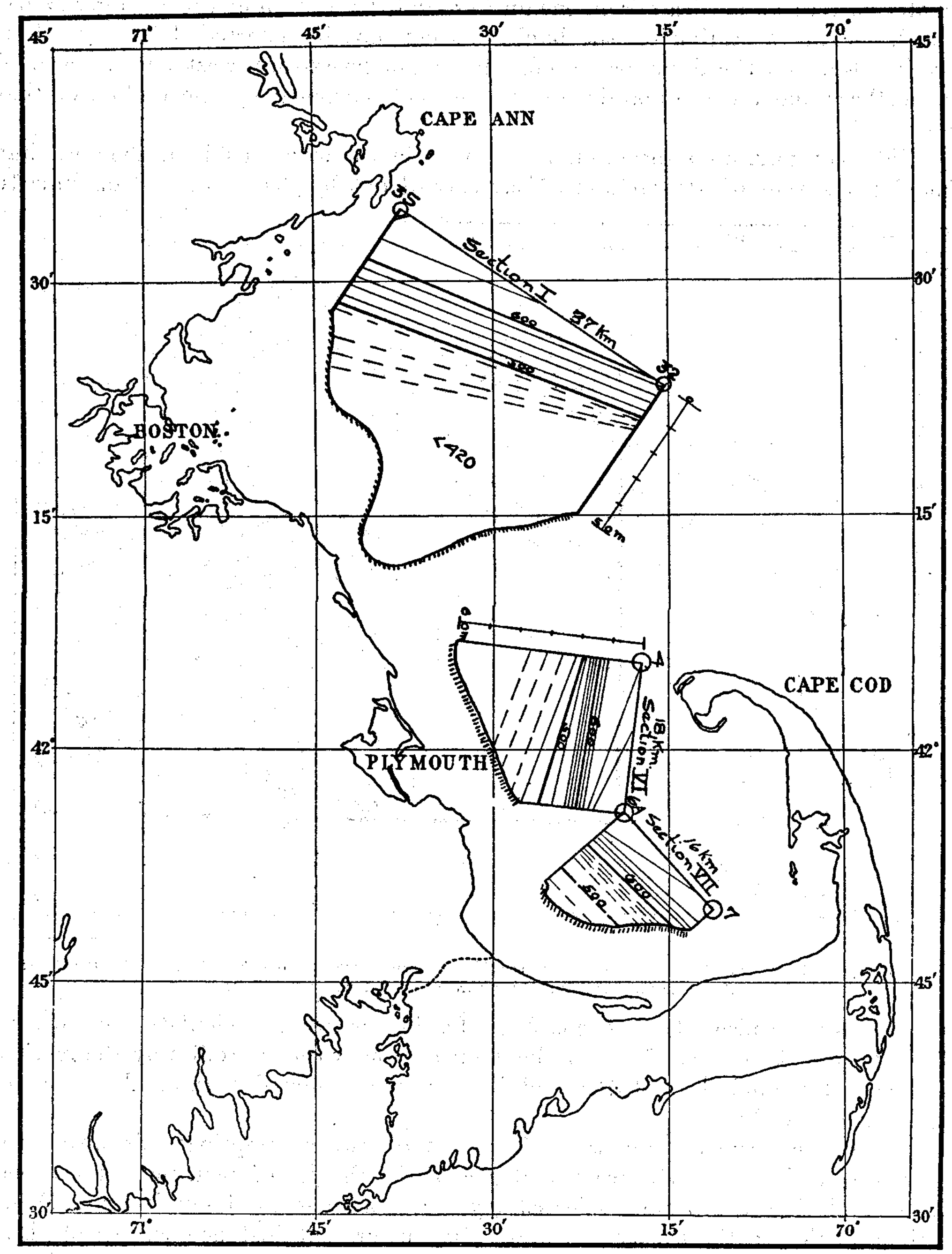

FIG. 198.—Specific volumes on three profiles in Massachusetts Bay, June 16 and 17, 1925. Calculated by R. Parmenter

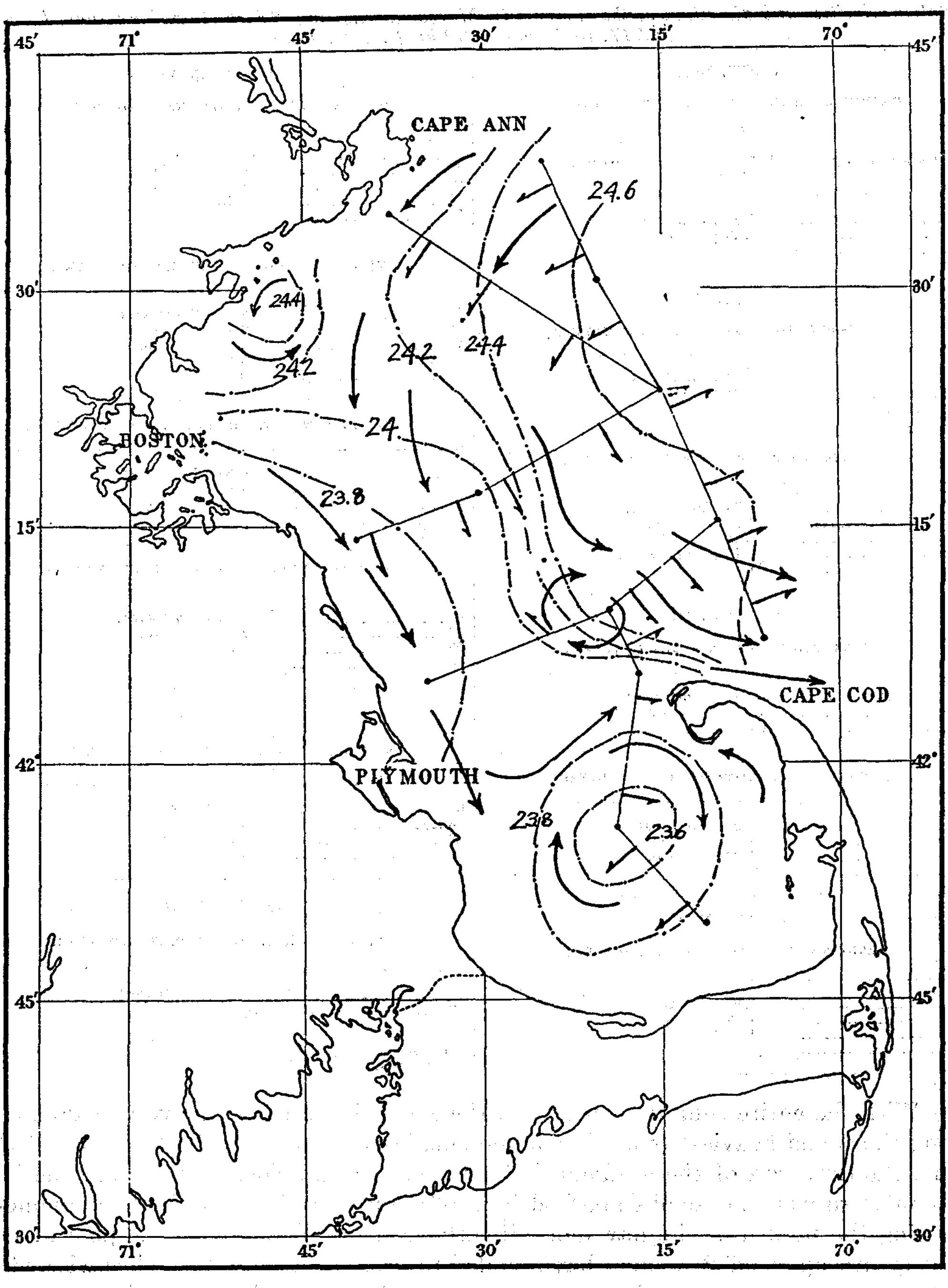

FIG. 199.—The single-barbed arrows show the direction of the gradient current, as calculated for Massachusetts Bay by R. Parmenter, June 16 and 17, 1925. The double-barbed arrows outline the nontidal circulation as it probably existed at the time. The broken curves give the density at the surface. For further explanation see p. 952

Relative velocities and directions of the currents in Massachusetts Bay, "Fish Hawk" stations, June 16 and 17, 1925, calculated by R. Parmenter

SECTION I

STATIONS 35 TO 32. DISTANCE, 37 KILOMETERS

Depth, meters	Velocity (cm. sec.)	Direction
0	5.16	Southwest.
10	3.43	Do.
20	(1)	

SECTION II

STATIONS 16 TO 18A. DISTANCE, 15 KILOMETERS

0	5.67	Southeast.
10	4.24	Do.
26	(1)	

STATIONS 18A TO 32. DISTANCE, 24 KILOMETERS

0	7.74	Southeast.
10	3.91	Do.
20	.63	Do.
40	.76	Northwest.
50	(1)	

SECTION III

STATIONS 14 TO 3. DISTANCE, 24 KILOMETERS

0	0.08[2]	Northwest.
10	1.40	Do
22	(1)	

STATIONS 3 TO 33. DISTANCE, 16 KILOMETERS

0	8.22	Southeast.
10	8.03	Do.
20	4.28	Do.
30	(1)	

SECTION IV

STATIONS 3 TO 4. DISTANCE, 8 KILOMETERS

0	1.92	Northeast.
10	4.98	Southwest.
20	4.47	Do
30	(1)	

SECTION V

STATIONS 30 to 31. DISTANCE, 15 KILOMETERS

0	6.94	Southwest.
10	4.18	Do.
20	1.62	Do.
40	.13	Do.
75	(1)	

STATIONS 31 to 32. DISTANCE, 15 KILOMETERS

0	2.09	Southwest.
10	2.79	Do.
20	2.29	Do.
40	0.00	
50	(1)	

STATIONS 32 to 33. DISTANCE, 16 KILOMETERS

0	6.33	Northeast.
10	4.69	Do.
20	2.41	Do.
50	(1)	

STATIONS 33 to 34. DISTANCE, 15 KILOMETERS

0	1.63	Northeast.
10	2.51	Do.
20	2.31	Do.
50	(1)	

SECTION VI

STATIONS 4 to 6A. DISTANCE, 18 KILOMETERS

0	7.77	East.
10	5.74	Do.
20	3.52	Do.
34	(1)	

SECTION VII

STATIONS 6A to 7. DISTANCE, 16 KILOMETERS

0	1.47	Southwest
10	(1)	

[1] Assumed stationary.
[2] Negligible.

With the entire column of water on the whole lightest (specific volume greatest) along shore and heaviest (specific volume smallest) off the mouth of the bay at the time, the direction of the gradient drift was clearly anticlockwise around the bay and outward past the tip of Cape Cod (fig. 199), but also with a southerly component crossing the mouth of the bay more directly from north to south. A pool of low density in Cape Cod Bay must have tended to produce a subsidiary clockwise eddy occupying most of the area between the Plymouth shore and Cape Cod.

The calculated directions and velocities also show a second but smaller eddy of the same sort centering over the southwestern edge of Stellwagen Bank, though this would not appear from the distribution of density at the surface.

Dynamic evidence thus suggests the persistence of the general southerly drift past this sector of the coast line through June, involving Massachusetts Bay, which is corroborated by the drifts of a considerable number of bottles that were put out in the bay by the *Fish Hawk* a month earlier.

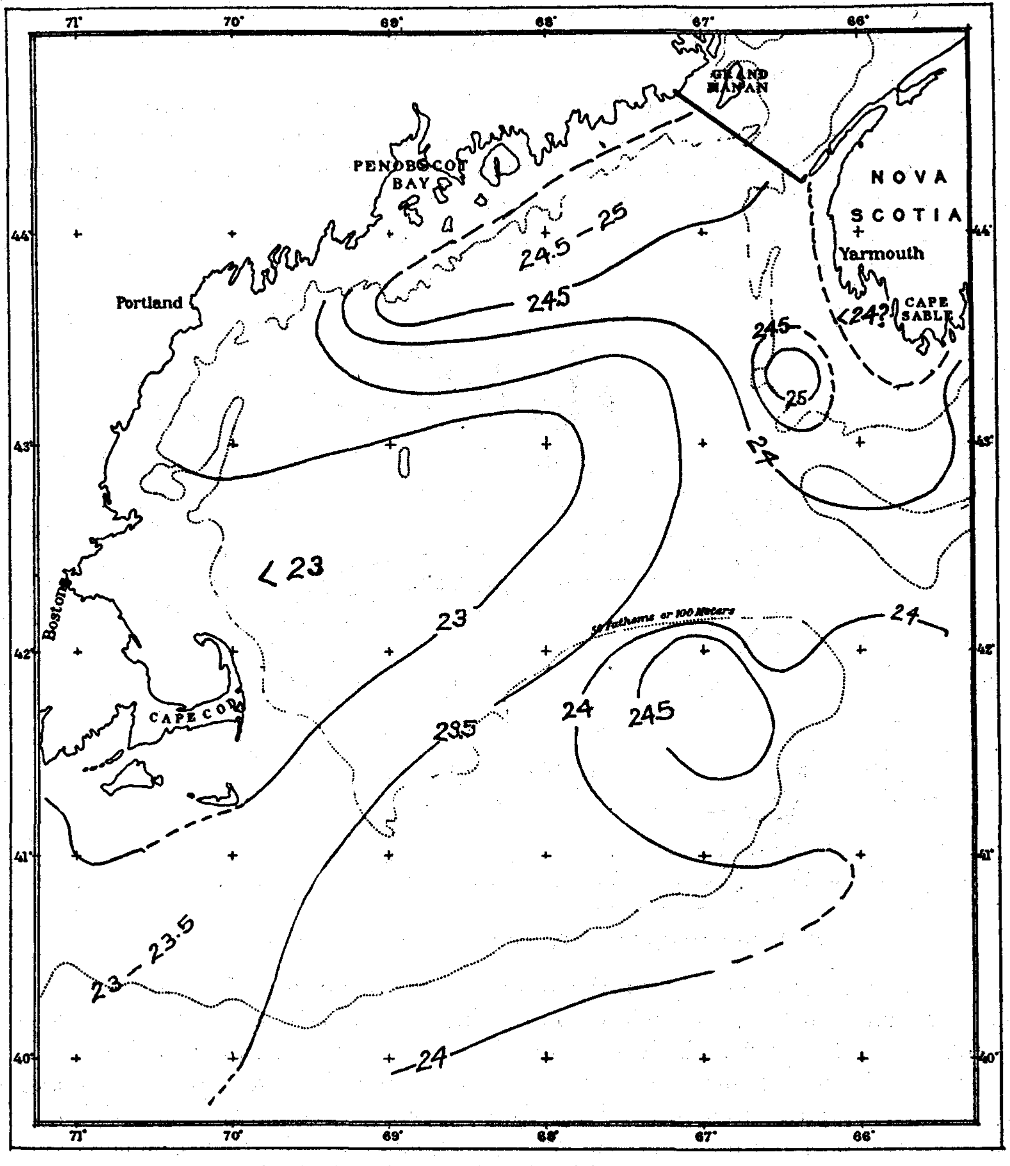

FIG. 200.—Distribution of density at the surface of the gulf, July and August, 1914

JULY AND AUGUST

The rapid solar warming of the surface over the western arm of the basin leads to the development of a pool of low density in the offing of Cape Ann by July and August (figs. 200 and 201). The eastern part of the gulf, on the other hand, continues high in surface density throughout the summer, because of the strong tidal currents that constantly mix the surface stratum, as it warms, with colder and more saline water from below (p. 928), and because the indraft of slope water of high salinity is directed into this side of the gulf. Consequently, the regional variation in the density of the upper 40 meters is wider in summer than at any other season, with the fundamental west-east gradation reappearing from year to year in essentially the same spacial relationship.

In April, and especially in May, the reader will recall, simple projection of the density contours at the surface mirrors the general dynamic tendency for the whole body of water in the gulf, regional distribution being essentially similar downward through the whole column. This, however, is not the case in summer, because the surface pool of low density in the offing of Massachusetts Bay is a superficial phenomenon. In fact, the surface contour lines run almost at right angles to those at 100 meters (fig. 202), which more nearly preserve the character of the preceding months. The actual surface drift in this side of the gulf is therefore the component of a rather complex screwing motion. In the northeastern part of the gulf, however, the surface state more nearly mirrors the regional distribution of density for the whole column.

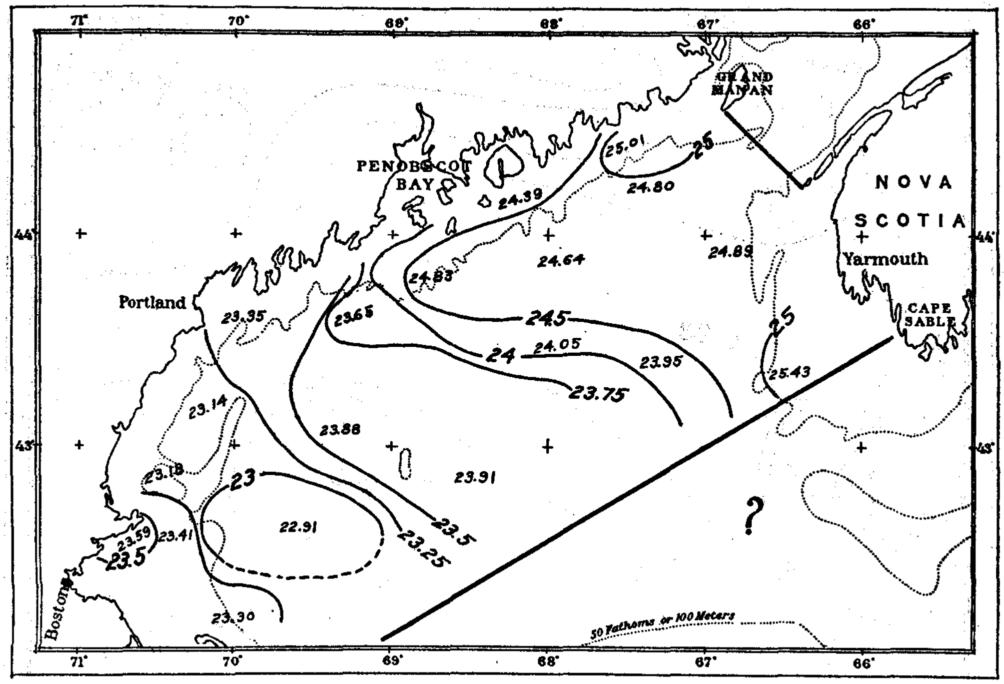

FIG. 201.—Distribution of density at the surface, for the inner part of the gulf, August, 1913

Unfortunately no one of our summer cruises has afforded the data needed for a satisfactory mapping of density for the whole area. In the only summer (1914) when the southeastern part of the area was surveyed, the coastal belt (more important dynamically) was neglected. In every case, too, allowance must be made for possible errors caused by the considerable period of time over which each survey extended. The rapidity with which the density of the upper stratum may be increased, if the surface be chilled by vertical circulation of any kind, makes it unsafe ever to lay any stress on small regional differences where tidal currents cause as much overturning of the water as they do in parts of the Gulf of Maine.

The accompanying dynamic chart for the summer of 1914 (fig. 203) shows the dynamic tendency toward circulation at the surface of the inner parts of the gulf and of the waters off Marthas Vineyard for August and of the Georges Bank-Browns Bank region for that July. Unfortunately, these two divisions of the picture are not strictly comparable because solar warming had been responsible for some slight decrease in the density of the surface stratum from the one month to the next, and for a very considerable decrease close to Cape Sable, where stations situated close together but occupied 17 days apart differed by 0.4 in density. Nevertheless, the general dynamic gradient proved so consistent for the gulf as a whole for the two months that it has seemed justifiable to neglect the time interval in drawing the contour lines; the more so since the heaviest centers for July and August proved almost exactly equal in dynamic height.

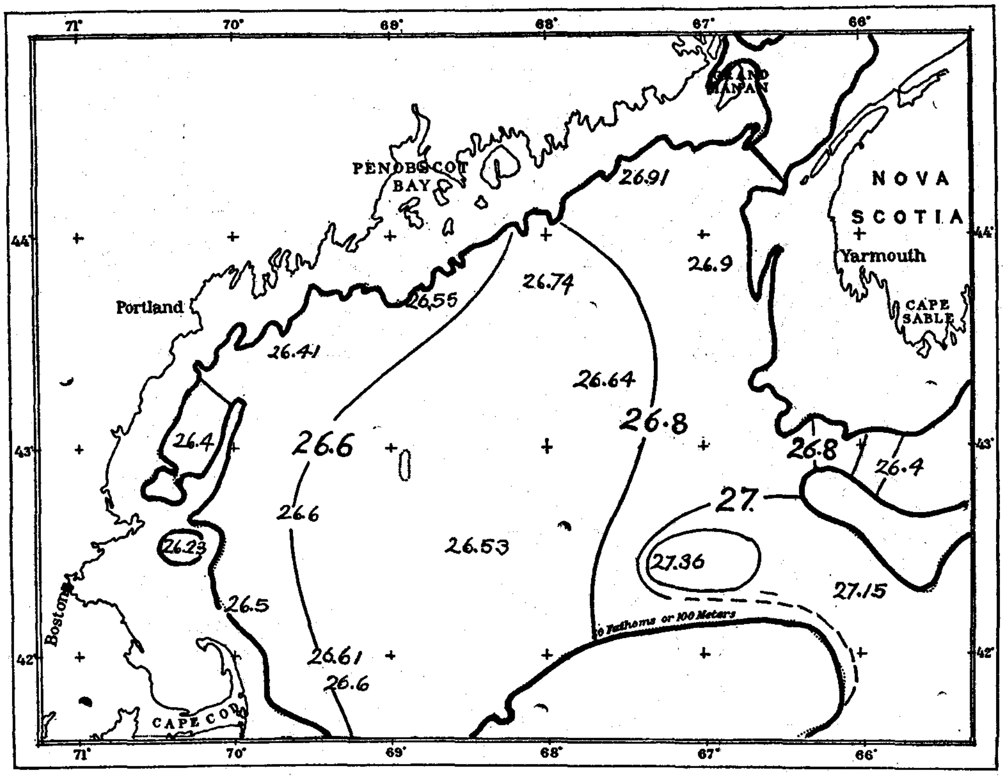

FIG. 202.—Density at 100 meters, July to August, 1914. Corrected for compression

If the chart, so combined, be indeed typical of the season (as seems likely from general knowledge of the temperature and salinity of the region), two centers of high density (indicated as "low" on the dynamic chart) are now to be expected—the one overlying Browns Bank, the Eastern Channel, and the water off the mouth of the latter; the other situated over the northeastern part of the basin; the two separated by a slight potential elevation of the surface. Contrasting with these "lows," which are obviously the vortices of anticlockwise circulation, is the high in the offing of Massachusetts Bay. A slight gradient, west to east, is also shown from the northern low toward Nova Scotia in August; a steeper gradient of the same order northward toward the coast of Maine. There is every reason to suppose that the water

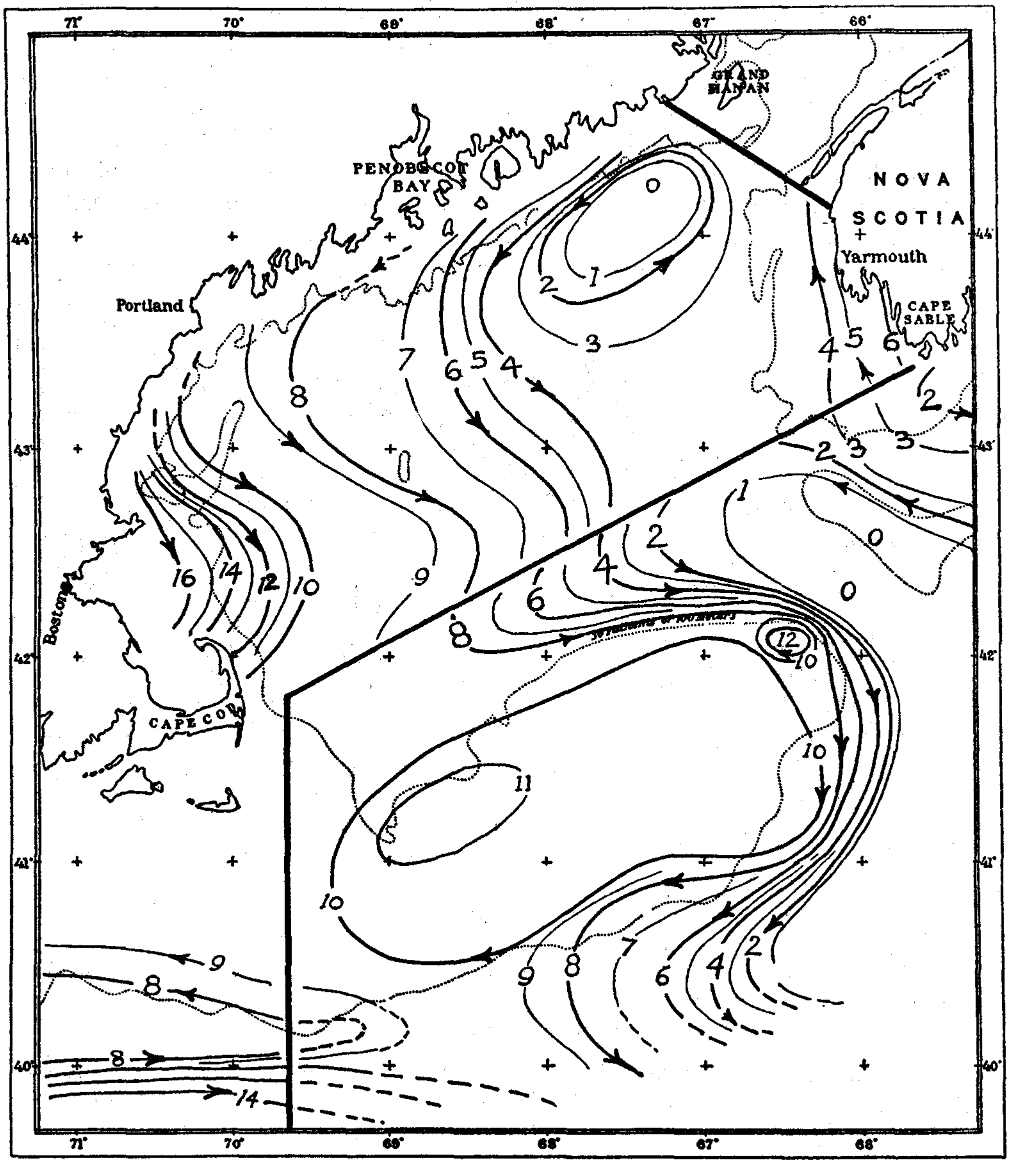

FIG. 203.—Dynamic gradient at the surface, July to August, 1914, referred to a base station in the Eastern Channel. The curves are for every dynamic centimeter. The picture south and east of the heavy dividing line is for July; north and west of it for August

was then lighter still (i. e., the surface potentially still higher) all along the coast westward from Mount Desert, where no observations were taken that summer.

Only in one small region did the dynamic contours for that July prove nonconformable to those of August—namely, in the immediate offing of Cape Sable. Here a slope rising from Browns Bank across the Northern Channel gave place to a potential dip next the cape in July, reflecting the high density of the cold water next the Nova Scotian coast reminiscent of the Nova Scotian current of a month or two earlier. Consequently, while the surface water over the Northern Channel was then drifting toward the gulf, that next the cape was drifting away from it; but the rising temperature of the next three weeks (combined with considerable freshening) so decreased the density of this relict water that by mid August a rising slope was recorded from German Bank in toward the cape, corresponding to the northerly drift toward the Bay of Fundy with which so many drift bottles have journeyed. Observations taken near Yarmouth, Nova Scotia, by Vachon (1918) in September, 1916, make it probable that in summer this sector of the coast line is normally fringed by water relatively lighter than is shown on the chart for 1914 (fig. 200).

The distribution of density in the Bay of Fundy in summer has been studied by Mavor (1923). Here the lightest water lies along the northern side in the upper 60 to 80 meters, the heaviest bottom water banking up in the central part of the basin in depths greater than about 100 meters. This type of distribution, as Mavor (1923, p. 364) makes clear, must tend to develop a surface drift from east to west toward the mouth of the bay along the New Brunswick shore. The "rising of the cold (below 7°) and salt (above 33 per mille) water in the middle of the section" indicates, as he remarks, an anticlockwise rotation of the bottom water guided by the contour of the slopes, which is consistent with the bottle drifts (p. 868).

So long as the dynamic contour of the surface of the gulf is of the general type shown on Figure 203, a generally anticlockwise type of circulation will tend to dominate the whole basin, centering some 40 to 60 miles offshore in the offing of Mount Desert Island, with a subsidiary eddy, likewise anticlockwise, involving the Bay of Fundy. The contour lines show that a southwesterly drift is then to be expected off Mount Desert Island and past Penobscot Bay, but one constantly tending offshore, veering rather abruptly southward and southeastward in the offing of Casco Bay and so out across the basin.

Off Cape Ann, too, the dynamic drift tended to the southeast in August, 1914; but a division was indicated there, with the coastal water recurving toward Cape Cod.

Comparison with the bottle tracks makes it evident that dynamic circulation of this type corresponds very closely to the drifts of the bottles set out off Mount Desert, as these have veered from southwest through south and east and so northward along the Nova Scotian coast (figs. 183 and 184). The center of this eddy movement, however, seems to have been situated a few miles farther south and west in 1923 than the dynamic chart (fig. 203) shows it for 1914.

These dynamic contours also correspond to the southeasterly component of the tracks of bottles set out off Cape Elizabeth (figs. 180 to 182) and with the fact that most of these turned offshore from the beginning and did not parallel the coast line southward toward Cape Ann, as happens earlier in the season.

It is not so easy to reconcile the continued drifts of these Cape Elizabeth bottles toward Nova Scotia and the Bay of Fundy with the dynamic contours, for the latter suggest that any driftage from the northern coast of the gulf that reached the central part of the basin would rather be drawn into the circulation around the heavy center in the Eastern Channel, and so be carried outward around the eastern end of Georges Bank. This, in fact, seems to have been the fate of some of the bottles set out off Cape Ann and of most of those set out off northern Cape Cod in 1923 (fig. 176). It seems reasonable, therefore, to conclude that by the end of July or first of August of most years the zone of demarcation between the eastward drift around the southern side of the northern heavy pool and the counter drift around the northern side of the southern pool is located somewhat farther south than it was in August, 1914—not far, in fact, from the line of monthly separation laid down on the chart for that year (fig. 203).

The distribution of density around the eastern slopes of Georges Bank affords a striking illustration of the necessity for taking account of the difference in depth between pairs of adjacent stations in the dynamic calculations, arbitrary though this correction be (p. 934). Without the inclusion of this factor (p. 934), the dynamic head between the low over the Eastern Channel and the high surface over the neighboring part of Georges Bank would have been only about 1 to 2 dynamic centimeters in July, 1914 (except for one station at the extreme edge of the bank—station 10226—where an isolated pool of low density was recorded). Inclusion of the difference in depth increases this gradient to about 10 dynamic centimeters, working out at a relative velocity of about 0.5 knot out of the gulf around the eastern end of the bank (except as interrupted by a subsidiary clockwise circulation around the light center, just mentioned), which is probably a closer approximation to the truth.

The dynamic gradient along the southern edge of Georges Bank for July, 1914 (fig. 203), offers an explanation for the fact that none of the bottles from the lines set out off Cape Ann and off northern Cape Cod, which have gone out of the gulf around the eastern end of Georges Bank, have been reported from west of the longitude of Cape Cod, when so many set out to the south of the cape have gone in that direction (p. 881; figs. 174 and 176). With the dynamic contours turning southward to sea from the eastern end of the bank, and with the surface gradient rising from longitude 67° to longitude 68°, the March state (fig. 188) is recalled.

The reasonable expectation with this dynamic distribution is that driftage leaving the gulf by this route would circle offshore somewhere abreast the eastern part of Georges Bank, to be carried toward the northeast, finally, with the so-called "Gulf Stream drift." It is probable, also, that at least three bottles that went to England and to Ireland from the Cape Ann and northern Cape Cod lines of 1923 (fig. 176) followed this route.

The whole area of Georges Bank was comparatively dead water in July, 1914, just as in March; consequently no dominant movement is indicated across it either into or out of the gulf, which is corroborated by the evidence of temperature and of salinity. The bank as a whole is therefore made the center of a clockwise type of dynamic circulation in July, just as the inner part of the gulf is of an anticlockwise type.

The dynamic state is not so clear for the southwestern part of the banks area in summer, where the rise in temperature during the time interval between the two cruises of 1914 (July 20 to 21; August 25 to 26) may have been more than counterbalanced by some encroachment of water of high salinity inward over the shelf. Consequently, the dynamic values for the offing of Marthas Vineyard for that August are not directly comparable with those taken farther east during the month preceding. However, no gradient is suggested sufficient to account for the repeated drifts of bottles westward around Nantucket Shoals from the vicinity of Cape Cod.

The dynamic relationship along the continental slope in the offing of Marthas Vineyard and eastward about to longitude 68° for July and August, 1914 (fig. 203), recalls the March state (p. 939; fig. 188) so closely that a low or dynamic trough, with the gradient rising to seaward as well as shoreward, may be taken as typical of this belt. Its circulatory implication has already been discussed (p. 939). At the date of our August profile for 1914 the calculated velocity of the easterly or "Gulf Steam" drift along the offshore edge of this low, and relative to the latter, was at least half a knot off Marthas Vineyard, or about the same as in March, 1920 (p. 939),[93] which corresponds very well with the average velocities reported in this sector of the so-called "inner edge of the Gulf Stream" by passing ships in summer.

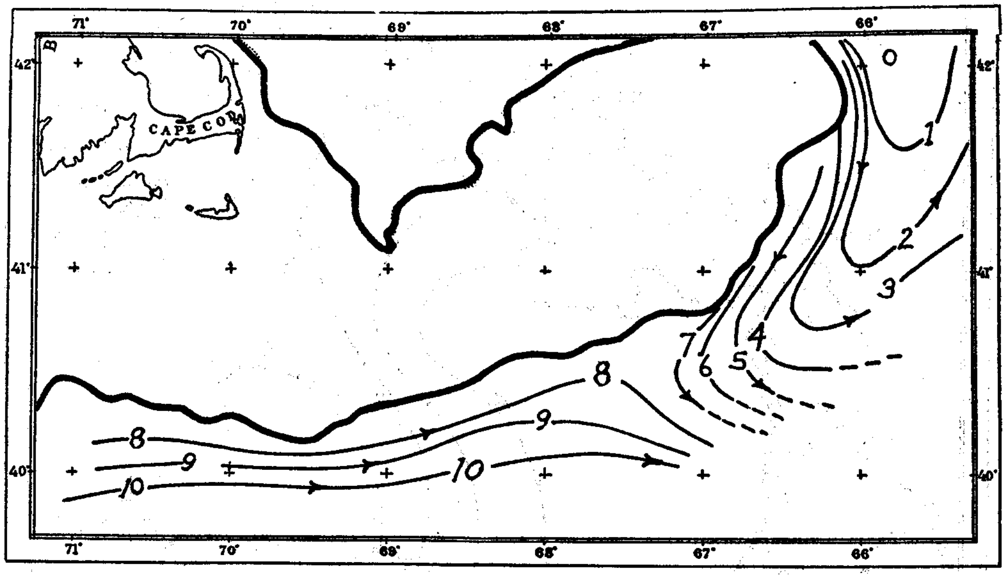

FIG. 204.—Dynamic gradient along the continental slope, bottom to 100 decibars, July to August, 1914. Contours for every dynamic centimeter

The dynamic contours at 100 decibars for that July and August (fig. 204) show the easterly set actually washing the continental slope to the west of longitude 68° then swinging offshore. We have here a ready explanation for the fact that water of high temperature and high salinity—the "warm zone"—usually bathes the slope along this western section but is separated from the slope farther eastward by the colder counter drift out of the Eastern Channel.

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[93] For the reasons stated above (p. 939), the calculation of velocity in this region can be taken only as a rough approximation.

In August, 1914, the bottom water of the gulf, as represented by the dynamic contours at 150 decibars (fig. 205), tended dynamically to drift across the basin from northeast to southwest—i. e., from the Nova Scotian slope and the offing of the Bay of Fundy toward the southwestern side of the basin, closely paralleling the March state (p. 941; fig. 190). The mechanism by which the deeps in the offing of Cape Ann are kept supplied with slope water that has previously entered the gulf is thus made clear. However, no direct dynamic drift seems to have been operative through the Eastern Channel in either direction at depths as great as this that July or August, contrasting with the strong outflow along its western side at the surface at the time (fig. 203; p. 958).

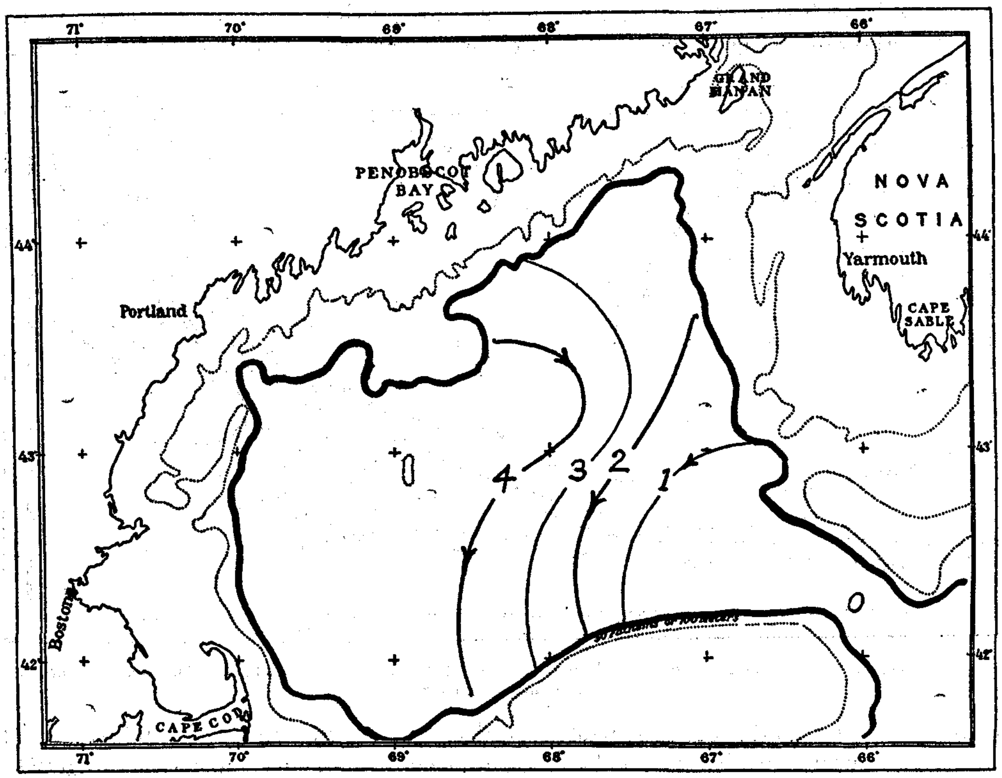

FIG. 205.—Dynamic gradient, bottom to 150 decibars, July to August, 1914. Contours for every dynamic centimeter

To test the constancy of the dynamic state of the gulf from summer to summer, a dynamic chart of the surface is also offered for August, 1913 (fig. 206, stations 10086 to 10106). Unfortunately this is not as trustworthy as the chart for 1914, because considerable interpolation of values, both for temperature and for salinity, was necessary in its construction. It is probable, also, that there was some error in the one or in the other, as recorded for two stations in the eastern side of the basin (stations 10092 and 10093), accounting in part for the contrast between the two. Nevertheless, the general gradient that results is so consistent, from station to station, that it may safely be taken as an approximation to the actual state of the northern and western parts of the gulf at the time.

Obviously, the center for the general anticlockwise gulf eddy lay considerably farther offshore in that summer than in 1914—according to the chart approximately 50 miles south of Mount Desert Island. The general drift in the northwestern and western sides of the gulf, then, more nearly paralleled the coast line from northeast to southwest, and so southward past Cape Elizabeth toward Cape Cod. Under these circumstances drifts might be expected more closely to approximate the tracks of the bottles that went from the Bay of Fundy to Cape Cod in 1919 (p. 870), rather than to show the offshore trend characteristic of the series set out off Mount Desert and off Cape Elizabeth in the summers of 1922 and 1923 (p. 895).

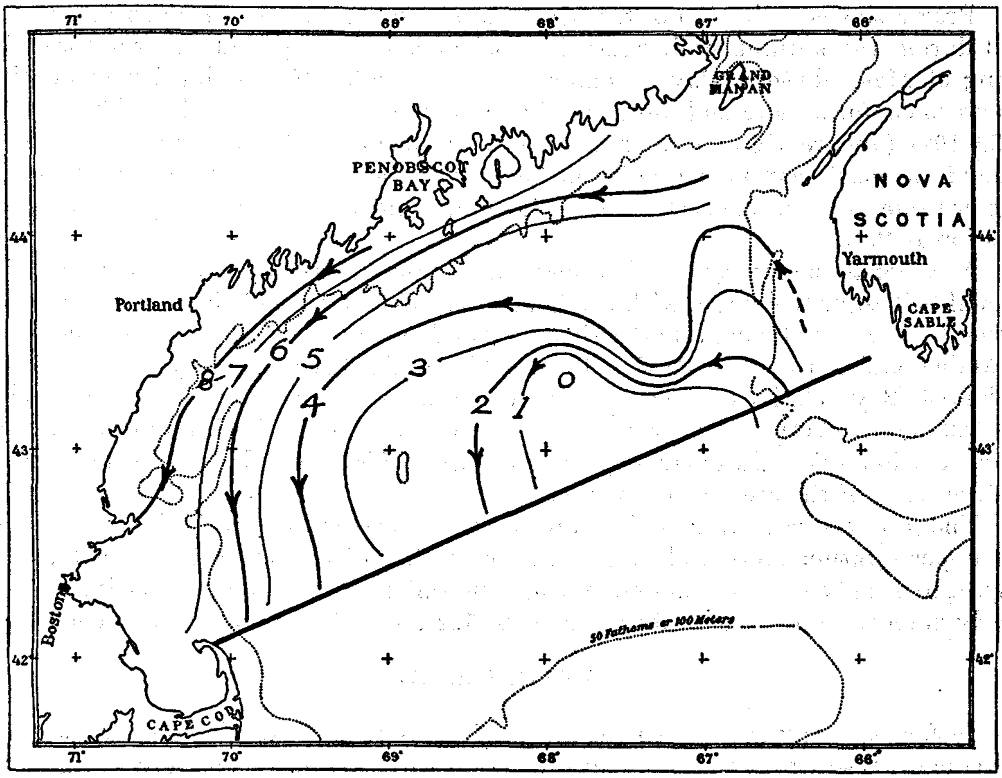

FIG. 206.—Dynamic gradient at the surface, August 4 to 20, 1913. Contours for every dynamic centimeter

In August, 1913, no data were obtained closer to the Nova Scotian coast than German Bank; but a higher surface in over the latter than over the basin suggests the northward drift to be expected on this side of the gulf. As it happens, this general scheme is obscured by a rather complex interaction between light and heavy water over the eastern side of the basin, which may, perhaps, mirror nothing more than some observational error at one or other of the two stations concerned (10092 and 10093).

Unfortunately, no observations were taken in the southern or southeastern parts of the area in August, 1913. However, the distribution of salinity (p. 767) makes it probable that the heavy water in the offing of Mount Desert was then entirely surrounded by lower densities to the south, and so separated from equally heavy water to be expected near the Eastern Channel and through the trough of the latter, just as was the case in July and August, 1914. The available data thus suggest that the dynamic tendency toward circulation continues regularly anticlockwise from summer to summer in the northern and northwestern parts of the gulf, though differences in the location of its center of revolution and in the regional distribution of density off the western shore are correspondingly reflected in the stream lines.

AUTUMN AND WINTER

Progressive equalization of temperature taking place in the shoaler strata of the gulf during the autumn obliterates the pool of low density that characterizes the offing of Massachusetts Bay in summer. As a result, the distribution of density comes to conform more and more closely to that of salinity. In the midwinter of 1920–1921 (apparently a representative season), the upper 100 meters were less dense around the coast than in the basin offshore, with the transition more abrupt in the western side than in the eastern, and the values highest in the offing of Cape Ann (station 10490).

A regional inequality of this sort must cause a dynamic tendency for the coastal belt to drift parallel with the land anticlockwise around the gulf, much as in spring (p. 942), producing a northerly set along Nova Scotia, westerly along the coast of Maine, and southerly from the offing of Cape Elizabeth past Cape Ann to Massachusetts Bay, relative to the underlying water mass. This latter (as represented by the 150-meter level) then proved nearly uniform in density horizontally (i. e., was nearly stationary). Unfortunately, no data are available for the southern or southeastern parts of the area for midwinter.

The progressive mixing of the water that takes place as winter advances makes the upper stratum more and more uniform, both horizontally and vertically, with respect to density as well as in temperature and salinity, until by February it becomes nearly homogeneous, as described above (p. 522), and the annual cycle is complete.

WIND CURRENTS

Seafarers have known, from the dawn of history, that the wind sets up surface currents often so strong that they must be taken seriously into account in navigation; and many a good ship has been wrecked from ignorance of the wind current.

In the Gulf of Maine the motive effect of the wind is made most apparent to the oceanographer by the upwellings of colder and salter water from below, which take place along its western margin when the surface water is driven offshore (p. 550). Every fisherman along our coasts knows from first-hand experience that strong winds, blowing from one quarter or another, strengthen the ebb at the expense of flood—or vice versa, as the case may be.

The dynamic principle according to which wind currents are produced is extremely simple: The wind drives the surface water before it, the motion of the latter being propagated to underlying strata by the internal friction of the water. Once in motion, the water, as Nansen (1902) and Ekman (1902) have pointed out, must be deflected by the effect of the earth's rotation. Nansen's (1902) observations on the drift of

Arctic ice, with subsequent studies of currents at lightships and analyses of wind and drift at localities widely separated in the Baltic, North Atlantic, Mediterranean, North Pacific, and Adriatic unite in proving that the wind drift does, in fact, average to the right of the wind in the northern hemisphere, to the left of it in the southern, as theory demands.

According to Ekman's (1905) more recent mathematical analysis, the surface drift in a free ocean of unlimited depth will be deflected 45° to the right of the direction of the wind in the Northern Hemisphere, more and more to the right with increasing depth, but decreasing correspondingly in velocity until a level (the so-called "frictional depth" is reached where the drift is opposite the wind but at only about one twenty-third the strength of the surface current. The depth of this level depends on the strength of the wind and on the latitude; theoretic calculation for homogeneous water of a specific gravity (1.025) approximating that of the shoaler water of the Gulf of Maine (Smith, 1926, p. 47, Table 14) locates it at 45 to 90 meters for the latitude of the Gulf of Maine, with winds ranging in strength from 15 to 20 nautical miles per hour (Beaufort scale, 3 to 4).

The Gulf of Maine lies within the belt of variable winds, frequently reversing in direction. The length of time required for the full development of a wind current is therefore important. This is affected by many factors; but Ekman's mathematical study with the measurements of wind and currents, which have been made at lightships in various seas, makes it almost certain that only a few days are required at the latitude of the Gulf of Maine. It is therefore reasonable to assume that winds prevailing from a given quadrant of the compass for 50 to 70 per cent of the time, such as actually blow over our gulf, are sufficiently constant in direction to play a major rôle in governing the circulation of at least the upper stratum of water, if not of the deeper levels.

If, then, the water of the gulf were homogeneous, free to move in any direction, and considerably deeper than the "frictional depth," moderate winds, blowing comparatively steadily from one general direction for a few days, should set the whole upper 45–90 meters in spiral. Actually, however, the vertical stability and generally stratified state of the water of the gulf tend greatly to limit the depth to which wind currents may be expected to penetrate downward.

The angular deviation of the wind current from the direction of the wind may also differ widely at sea from the theoretic expectation. If the depth of water be less than the frictional depth, the angle will be less; and while this limitation does not affect the development of wind currents in the basin of the gulf, it does affect the coastal belt out, say, to the 40 to 50 meter contour. The vicinity of the coast line, with the contour of the bottom, also governs the directions which surface drifts, set in motion by the wind, must actually follow. The effects of these influences have also been attacked mathematically by Ekman (1905); but, as Krümmel (1911, p. 469) has emphasized, so many variables, which can not be exactly measured, enter in that the surface currents which the wind has actually been found to set up in other coastwise localities, in comparable latitudes, still afford the best available indication of what is to be expected in the Gulf of Maine.

Long series of measurements of the currents at various lightships in the Baltic[94] have shown the nontidal surface drift averaging about 30° to the right of the wind, and much more often to the right than to the left. Analysis by Forch (1909) of the relationship between the wind in the eastern Mediterranean, and the drifts there, as reported in ships' logs for the Arabian Gulf by Gallé (1910), have brought out a corresponding tendency for the current to set about 40 to 60° to the right of the wind.[95] According to the current tables published by the United States Coast and Geodetic Survey (1923), local winds off the eastern coast of the United States likewise produce currents setting about 20° to the right of the wind direction at a velocity about 1½ per cent of that of the wind.[96]

The Baltic measurements just mentioned had already proved that the current sometimes sets to the left of the wind, due, no doubt, to the effect of the coast line. This relationship between coast line and wind current has been brought out very clearly by a recent investigation of the currents at five lightships along the Pacific coast of the United States by the Coast and Geodetic Survey. For a detailed account of these observations the reader is referred to Marmer (1926 and 1926a). In summary they are as follows: Offshore winds and winds parallel to the shore, if having the latter to the left, produce surface currents averaging 20 to 25° to the right of the wind; but if the wind blows against a coast line lying to the right of its track, at an angle of 45° or less (i. e., a southwest wind against a north and south shore line), the current is deflected to the left as it strikes the coast, as might naturally be expected from ordinary observation on the behavior of the tides.

The observations tabulated below (p. 964) for Portland lightship also show the nontidal current drifting to the right of the wind during months when winds blowing toward the southern half of the compass favor the dominant southerly set. When the wind blows toward the north or northeast against the current, the latter may or may not be reversed. If it is, the resultant set may be either to the right of the wind or slightly to the left of it, depending on the complex interaction between direction and strength of wind, nontidal set, and the trend of the coast line.

Dominant surface set and prevailing wind at Portland lightship

Month	Current [a]	Wind [a]	Current to right	Current to left
1913				
October	S. 67° W.	S. 2° E.	69°	
November	S. 31° E.	N. 84° E.	65°	
December	S. 11° W.	S. 50° E.	61°	
1919				
June	S. 36° W.	N. 3° E.		147°
July	N. 62° E.	N. 28° E.	34°	
August	S. 74° W.	N. 33° E.		139°
September	N. 47° E.	N. 27° E.	20°	
October	N. 58° E.	N. 73° E.		15°

[a] The directions are those toward which winds and currents set. For full data see pp. 861 and 862.

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[94] Dinklage (1888), Witting (1909), summarized by Krümmel, 1911, p. 451.

[95] For theoretic discussion and explanation of modern mathematical methods of calculating wind currents see Ekman (1905), Krümmel (1911), Sandström (1919), and Smith (1926).

[96] This statement has as its basis current measurements taken at a large number of localities, some of which are discussed above (p. 963).

The following tables, supplied by the United States and Canadian weather bureaus, show the prevailing winds, by months, for several stations around the coast of the gulf and over the latter.

Average percentage of winds from each direction (10 years, 1911 to 1920)

BOSTON, MASS.

Month	North	North-east	East	South-east	South	South-west	West	North-west
January	10	5	2	6	3	23	28	23
February	11	5	4	3	5	17	31	24
March	12	7	6	6	8	17	24	20
April	9	11	12	7	6	16	18	21
May	8	9	13	8	8	21	18	15
June	10	9	15	6	6	23	18	13
July	5	6	10	5	8	33	21	12
August	7	8	10	7	11	25	18	14
September	11	7	6	8	9	22	19	18
October	9	7	7	7	10	23	20	17
November	10	4	4	4	7	20	32	19
December	10	4	3	3	5	16	32	27
Average for 3 winter months	10	5	3	4	4	19	30	25
Average for 3 summer months	7	8	12	6	8	27	19	13
Average for year	9	7	8	6	7	21	23	19

PORTLAND, ME.

January[1]	21	6	1	3	6	19	19	24
February[1]	22	4	1	4	8	17	19	24
March	17	6	3	5	13	15	18	23
April	18	12	6	4	13	13	14	20
May	12	10	9	7	21	14	12	15
June	10	11	10	8	18	14	13	16
July	11	7	7	6	25	19	15	10
August[1]	9	7	9	8	23	18	11	14
September[1]	14	7	4	5	18	19	12	20
October	15	4	4	6	15	22	15	19
November	18	4	2	4	8	24	19	21
December	21	4	1	3	5	21	19	26
Average for 3 winter months	22	5	1	3	6	19	19	25
Average for 3 summer months	10	8	9	7	22	17	13	13
Average for year	16	7	5	5	14	18	15	19

EASTPORT, ME.

January	11	7	5	4	8	17	27	21
February	11	9	4	4	6	16	28	22
March	10	8	5	5	13	17	20	22
April	12	14	8	3	17	16	13	17
May[1]	10	11	6	3	30	16	9	14
June	6	12	7	4	31	15	11	14
July[2]	6	9	3	2	40	21	8	9
August[1]	4	9	4	3	38	18	10	13
September[1]	9	6	5	3	22	21	12	21
October	10	6	5	2	22	20	14	21
November	10	9	4	3	9	24	21	20
December	14	7	6	4	6	13	27	23
Average for 3 winter months	12	8	5	4	7	15	27	22
Average for 3 summer months	5	10	5	3	37	18	10	12
Average for year	9	9	5	3	20	18	17	18

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[1] One per cent calm.

[2] Two per cent calm.

Average percentage of winds from each direction (10 years, 1911 to 1920)—Continued

YARMOUTH, NOVA SCOTIA

Month	North	North-east	East	South-east	South	South-west	West	North-west	Calm
January	15	12	10	9	6	10	6	30	2
February	16	13	9	8	7	7	7	29	4
March	17	9	7	7	9	11	10	26	4
April	13	10	10	8	9	12	13	20	5
May	11	6	6	10	16	18	15	16	2
June	8	3	6	8	20	20	15	14	6
July	5	3	4	6	20	31	14	8	8
August	6	2	5	6	20	23	11	14	13
September	13	7	6	7	14	15	11	15	12
October	15	8	9	7	14	18	10	13	6
November	15	12	10	5	6	14	11	23	4
December	16	14	10	8	5	10	5	30	2
Average for 3 winter months	16	13	10	8	6	9	6	30	-------
Average for 3 summer months	6	3	5	7	20	25	12	12	-------
Average for year	13	8	8	7	12	16	11	20	-------

Five-degree square, including Gulf of Maine, from pilot charts

Month	Percentage of winds from the most frequent quadrant	Month	Percentage of winds from the most frequent quadrant
January	North to west, 63.	July	West to south, 68.
February	North to west, 73.	August	West to south, 50.
March	North to west, 57.	September	Northeast to northwest, 49.
April	North to west, 58.	October	North to west, 58.
May	West to south, 50.	November	North to west, 64.
June	West to south, 45.	December	North to west, 63.

These tables may be briefly summarized as follows:

Along the western and northern shores of the gulf the wind blows most often between southwest and north in winter, averaging about northwest. In summer southwesterly and southerly winds prevail. On the eastern side of the gulf the wind averages more westerly (south to northwest) in summer, northerly (between northwest and northeast) in winter. Over the offshore waters of the gulf, where the direction of the wind is not so much influenced by the diurnal warming and cooling of the land, the prevailing winds are between west and north (though with frequent reversals) from November to April; between west and south from June to August; more variable in late spring and again in early autumn.

In summer, by theoretic expectation, winds of this character would tend to produce a general drift of the surface water about 20° to 45° to the right of the octant, north to northeast—i. e., toward the northeast and east. Thus, the prevailing winds favor the general drift out from the western side of the gulf and eastward across the southern part of the basin toward Nova Scotia, which prevails at that season (p. 974). Striking Nova Scotia, this wind current would tend to bank up against the coast, raising the level of the sea slightly. Thereupon hydrostatic forces are brought into play, dynamically, against the wind; but any resultant movement of the water out from the land being in turn deflected to the right by the earth's rotation, a northerly drift might be expected to result along Nova Scotia, and in this instance theoretic expectation agrees so well with the drifts of bottles actually recorded that the prevailing southwesterly winds of summer certainly assist the surface drift from south to north, which characterizes the eastern side of the gulf at that season, though as certainly not the only motive force for it.

Thus, the wind then tends to act as a motive force for the southern and eastern sides of the Gulf of Maine eddy.

It is obvious, however, that no matter how steadily the wind blew from the southwest it could not drive the entire surface of the gulf eastward unless the water were nearly enough homogeneous to allow a sinking current to develop in the eastern side, with the deeper stratum so fed flowing back from east to west, to well up again, in turn, in the western side. Circulation of this sort probably does take place to some extent along the Nova Scotian side of the gulf, in the Bay of Fundy, and along the coast of Maine east of Mount Desert, where active tidal currents keep the water so thoroughly stirred that it has little stability at most times of year. It is certain, also, that offshore winds do cause more or less upwelling along the western shore line, but the basin of the gulf as a whole, with its western and northwestern margins, is so stable vertically that hydrostatic forces very strongly oppose any such "jibing," as Sandström (1919) terms it. Consequently, any constant movement of the surface water northward toward the Bay of Fundy would tend to cause an "overflow" in the shape of a westerly drift along the coast of Maine—i. e., *against* the winds prevailing in summer.

It is obvious that if the water be in stable equilibrium, southwesterly winds might or might not set a closed circulation of this type in motion, depending on their relative strengths and constancy in various parts of the gulf; depending, too, on the balance in various parts of the gulf between the hydrostatic forces opposing jibing and the tendency of the wind to cause that process, as just explained. To value these several factors will require a knowledge of the gulf and of its winds much more intimate than can yet be claimed. It is certain that with winds reversed as often as they are over the gulf the balance varies constantly. However, the preceding analysis does make it clear, I think, that any eddying circulation which the southwesterly winds of summer might set up in the surface stratum of the gulf would shortly assume the anticlockwise character that, by evidence of more direct sorts, does actually dominate its basin. Consequently, the summer winds parallel the hydrostatic forces set in operation by regional inequalities of density in their general effects to this extent. On the other hand, the current flowing southward and out of the gulf past Nantucket Shoals, which forms part of the overflow from the gulf, is at right angles to the potential wind drift, hence holds its dominant set in spite of the prevailing wind. Neither can the wind be held responsible for the westerly drift of slope water along the continental edge in summer, because this current sets directly against the drift which the prevailing southwesterly winds would tend to produce there.

The wind current, as it extends its effects deeper and deeper below the surface, will turn more and more to the right of the wind (losing, also, in velocity by geometric progression); also, with increasing depth the gulf becomes more and more nearly inclosed, so that any currents, however set in motion, are more and more directed by the contour of the bottom.

The depth to which currents of wind origin do actually penetrate in the Gulf of Maine is therefore of immediate interest. Unfortunately, no mathematical method yet suggested can measure this, even approximately. However, it is certain that the stable state of the water of most parts of the gulf ordinarily confines wind currents to a stratum much shoaler than the theoretic "frictional depth" as calculated by Smith for homogeneous water at corresponding latitudes (p. 963).

With an average wind strength of 3 to 4, by the Beaufort scale (a fair average from the gulf in summer), this depth is set by him as about 43 to 70 meters at latitudes 40° to 50°. It is not likely, however, that the wind ever sets water as stable as that of the western side of the gulf in motion half so deep as this during the brief periods when it blows steadily from any given direction at a strength as great as 4, on the Beaufort scale (about 20 nautical miles per hour), during the summer months. With the more usual summer breezes no stronger than 10 to 15 miles per hour (2 to 3 on Beaufort scale), the frictional depth must be even smaller. Frequent reversals of the wind direction, with periods of calm, also further hinder the propagation of wind currents downward into the underlying water. On the whole, then, it is unlikely that wind currents are effective deeper than 10 to 20 meters in the gulf in summer, except perhaps during brief periods of windy weather. Even if this limitation be too small it leads to the important conclusion that whatever currents may be set up in the gulf in summer by the wind are confined to a very thin superficial stratum, and that the dominant anticlockwise and estuarine circulation of the deep water below the 40 to 50 meter level is caused by hydrostatic forces and by the tidal oscillations (p. 970).

The pulses of slope water into the gulf via the trough of the Eastern Channel are equally independent of the wind.

In winter the winds of the gulf of Maine area blow stronger (average about 3 to 5 on the Beaufort scale), and the prevailing quarter is northwest (p. 966). Winds of this character tend, theoretically, to drive the surface water of the whole gulf out to the southward, toward the open sea. Probably it is this prevalence of strong offshore winds all along the North American seaboard, from Chesapeake Bay to the Gulf of Maine, during the cold season, which is primarily responsible for the recession of the tropical water from the edge of the continent during autumn and winter, their cessation allowing its inshore movement in summer. The prevailing northwest winds of winter tend, therefore, to strengthen the dominant southerly drift along the western side of the gulf. With the coast line trending north and south, the deflective effect of the earth's rotation gives a long-shore character to currents caused by winds from this quarter, except so close in to the land that the whole depth of water is less than the frictional depth. Under these last conditions (by Ekman's calculation) the wind current will set more nearly with the wind than in deeper water offshore.[97]

Consequently, the prevailing winter winds from the northwest quadrant do not tend to cause any general or constant upwelling along the coast sector from Cape Ann to Cape Elizabeth except within 2 to 3 miles or so of the land, where the water is shoaler than one-fourth the assumed frictional depth of 50 meters. This is corroborated by our station data, but upwellings, such as are actually recorded (p. 588), necessarily tend to follow these same west to north winds along the north shore of Massachusetts Bay. This same tendency for water to well up from below must operate spasmodically throughout the winter all along the coast of Maine, where

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[97] Theoretically, 21.5° to the right of the wind, if the depth of water be one-fourth the frictional depth.

prevailing winds (and the strongest winds), between west and north, drive the surface water offshore to the southward.

By this reasoning wind currents go far to explain the very interesting fact that in April the freshening effect of the spring freshets is so much more evident (in lowered salinity at the surface) along the coast sector west and south of the Kennebec than it is off Penobscot Bay (fig. 101). The discharges from the former, from the Saco, and from the Merrimac, driven southward by the prevailing northwesterly winds of March and April, parallel the trend of the coast and so preserve the identity of the coastwise belt of low salinity. Off Penobscot Bay, however, the more or less active upwelling that must follow this same southerly drift off this west-east coast line, combined with tidal stirring, tends to prevent the development of so fresh a band next the land, but at the same time to carry the least saline water farther out from the land. The distribution of salinity at the surface for March and April, 1920 (figs. 91 and 101), is of this sort.

It is probable that the development of a tail of very low salinity from the St. John River southward across the Bay of Fundy in April (p. 808) similarly reflects a southerly set caused by the northwest winds, which often blow strong there during the first month of spring, though their average direction veers through west to southwest during April.

The pool of low-surface salinity spreading out to the southwest from Nova Scotia, which appears on the surface chart for March, 1920 (p. 703; fig. 91), likewise finds plausible explanation as a wind-driven drift out from the bays south of Yarmouth, where northerly winds prevail in February (p. 966).

The effects of the winter winds are more puzzling in the eastern side of the basin of the gulf, where prevailing west-north winds tend to produce a southeasterly or southerly drift at the surface, but where the evidence of salinity and temperature points to a movement in just the opposite direction—i. e., northerly toward the Bay of Fundy in winter as well as in summer (p. 910).

It is evident here that although strong northerly winds may and no doubt do temporarily drive the surface water southward, the general dominant drift is caused not by the wind but by other forces (p. 976) strong enough to overcome the wind effect in the long run. Consideration of the depth to which wind currents may be set in motion corroborates this conclusion, because the frictional depth of the average winter wind of about 4, on the Beaufort scale, is theoretically only about 67 meters. Actually, the water of the eastern side of the gulf not being homogeneous, the depth of the wind current will be something less than this—perhaps 50 meters with the state of stability prevailing in winter. The thickness of the stratum which the wind can set in motion at an appreciable rate is still less.

According to the long series of observations on wind and current that have been carried out by the United States Coast and Geodetic Survey, the velocity of the wind current is 1.5 to 2 per cent that of the wind—say, about 0.4 knot, with a wind of 4 (Beaufort scale, 20 nautical miles per hour). Smith's table of theoretic velocities (Smith, 1926, p. 46, Table 8), applied to a current of this strength with assumed frictional depth of 50 meters, gives a residual current of only 0.2 knot at a depth of 10 meters, about 0.15 knot at 20 meters, and 0.07 knot at 30 meters. Theoretically (in a free ocean), in the example just stated the current at 10 meters should set 36°

to the right of the surface current, the water at 20 to 30 meters 72° and 108° to the right of it, respectively.

This calculation shows that even in winter wind currents are virtually negligible in the Gulf of Maine at depths greater than, say, 20 meters, and so weak at 10 to 15 meters that they can oppose but little resistance to hydrostatic forces or to tidal oscillations (as deflected by the earth's rotation), which may tend to drive the water in the opposite direction.

The general effect of the wind on the circulation of the gulf may be summarized as follows: In summer the prevailing southerly-southwesterly winds tend to maintain the anticlockwise circulation of the surface water, so far as they are effective at all in producing a constant circulation. It is probable, also, that the easterly set caused by the wind is chiefly responsible for the accumulation of the surface pool of high temperature, though low salinity, in the offing of Massachusetts Bay, which is characteristic of July and August. The outflow that takes place southward past Cape Cod and over the eastern end of Georges Bank, however, is against the prevailing wind. In winter the prevalent northwesterly winds assist the southerly drift in the western side of the gulf and are the chief cause for the wider dispersal of water of low salinity off its northern shore than off the western, but the general movement of water inward (northward) along the eastern branch of the basin is contrary to the wind.

Winter as well as summer wind currents are confined to the upper 10 to 20 meters. Consequently the dominant circulation of the deeper strata does not receive its motive power from this source.

HORIZONTAL TIDAL OSCILLATIONS AS DEFLECTED BY THE EARTH'S ROTATION

Huntsman (1923, 1923a, and 1924) recently has suggested that the tidal oscillations deflected by the effect of the earth's rotation are the chief motive force for the great eddies, anticlockwise and clockwise, that occupy the basins and circle about the islands and submarine banks in high latitudes. In his own words (Huntsman, 1924, p. 278), "the rotation of the earth" acts "as an imperfect valve in diverting the ebb and flood toward opposite sides of the channels and basins," thus causing a balance of inflow on the one side, of outflow on the other.

That the earth's rotation must exert a deflective effect on the tidal currents is beyond dispute. It is equally clear that if the oscillatory (back and forth) movement of the tides of any partially inclosed basin be altered by any agency into a progressive forward movement, the current, like any other, will be held against the right-hand bank in the northern hemisphere by the deflective force of the earth's rotation, and thus circulate anticlockwise, as Huntsman states. Furthermore, the deflective effect of the earth's rotation as it affects the tidal oscillation, if effective at all in this respect, must be most definitely so in regions where tidal currents attain considerable velocities at the strength of flood and ebb, as they do in the Gulf of Maine.

Beyond stating this proposition and certain applications of it to definite regions, Huntsman has not yet published any discussion of the dynamic principles involved, nor am I able to give it the physical analysis necessary for its proof or disproof.

However, there are certain grounds for concluding that Huntsman's theorem is probably effective in basins sufficiently inclosed, and that if so, the tides and earth rotation combined must have an unceasing pumping effect, working season in and season out on the following principle:

In the open sea, with no barrier to the free movement of the water, the rotation of the earth will merely change the track of ebb and flood (if flowing back and forth with equal velocity) from a right line to a closed ellipse; but in an inclosed basin, open to the tides only at one side, the case becomes altered by the fact that when the tide is flowing in the water is confined and prevented by the right-hand shore from eddying to the right. Consequently, the band of water closest the land on that side must either flow farther in, parallel to the coast, than it would if unconfined, or it must rise higher against the bank. No doubt both results actually follow. When the water next the land is so diverted from its normal path water farther out toward the center of the basin is correspondingly prevented from eddying to the right. Consequently, the effect of the shore line, in turning the flood tide to the left from the track it would follow if free to flow in any direction, extends far out to sea from the confining bank against which it presses. Under such circumstances the deflective effect of the earth's rotation tends to transform what is fundamentally an inshore current into a drift flowing into the basin in question, paralleling the shore line.

In the opposite side of the basin, which lies to the left of the flood tide, setting inward, this deflective force tends to turn the inflowing current away from the shore; consequently, it is reasonable to assume that the flood will not flow as far inward as it would otherwise. When the tide begins to ebb out of the basin conditions naturally are reversed, the ebb being driven against the coast, which is to the right of it (but to the left for the flood), and so carried farther out, but turned away from the side against which the flood was pressed as it flowed in.

The mobility of the water makes the picture exceedingly difficult to visualize or to represent by any diagram, and very likely complicated by vertical movements screwing forward, which I can not attempt to reconstruct; but as a net result it is reasonable to expect the flood to flow in farther than the ebb makes out in that side of the basin which is to the right of an inflowing current, and for the ebb to flow out farther than the flood makes in, in the opposite side. With a differential of this sort established an eddying movement would necessarily follow, forced to assume anticlockwise form by the confining shore line, in place of the clockwise character which the rotation of the earth would give it if not so opposed by the coast line or by the contour of the bottom. Translated into terms of the Gulf of Maine this would call for a dominance of flood over ebb (hence a northerly component) in the eastern side and a dominance of ebb over flood (i. e., a southerly component) in the western, such as has actually been demonstrated by drift bottles and by measurements with current meters.

Tidal currents in the gulf of Maine, the reader will recall, run nearly as strong right down to the bottom of the trough as they do at the surface. Consequently, Georges Bank, confining the basin on the south, should act as a coast line toward the deep tidal circulation, producing a west-east drift paralleling its northern slopes, if the foregoing analysis be correct. Here, again, the theoretic expectation is actually reproduced by the drifts of bottles that have crossed the southern side of the gulf from west to east (p. 886), corroborating Huntsman's (1923a, p. 18) conclusion that the dominant circulation in basins of this sort is kept in motion by the deep currents, not by the movements of the surface water. The clockwise drifts, which have been found to circle (or partly circle) several of the submerged banks (Georges, for instance (p. 974), and Nantucket Shoals), are also equally good evidence of dominance of the general circulatory scheme by the current flowing over the bottom, which the banks deflect just as islands would.

SUMMARY OF THE HORIZONTAL, NONTIDAL CIRCULATION OF THE GULF OF MAINE

The nontidal circulation of the Gulf of Maine (fig. 207) is essentially estuarine in type, as might have been expected from the contour of its bottom as well as from the trend of its coastline and from the large volume of fresh water discharged from the rivers tributary to it. The very considerable outflow from the gulf takes place at and near the surface—southward and westward past Nantucket Island and Shoals, in part, but in part as a clockwise movement circling around the eastern part of Georges Bank.

The evidence marshaled in the preceding pages—measurements with current meters, drifts of bottles, temperatures, salinities, distribution of the plankton in the superficial waters, and dynamics—can be harmonized with one type of dominant circulation only—a general anticlockwise eddy around the basin of the gulf. The demonstration of this, named by Huntsman (1924) and by me the "Maine" or "Gulf of Maine" eddy, with all it implies in its biological bearing, is perhaps the most interesting result of the joint explorations of the gulf.

The circulatory features most clearly established within the gulf are as follows:

The eddying drift is operative throughout the year but differs in velocity, and generally in detail, from season to season. It is also complicated by subsidiary eddying movements in the Bay of Fundy, Massachusetts Bay, Vineyard Sound, around Nantucket and Nantucket Shoals, and around and over Georges Bank, which are clockwise around these shoals but anticlockwise in the bays and basins, as Huntsman has shown to be the rule in northeastern American waters.

In the late summer and early autumn, when our information is the most extensive (fig. 207), the surface stratum of the inner part of the gulf eddies anticlockwise around an area of high density, the precise location of which shifts, from summer to summer, from the offing of the Bay of Fundy to a center in latitude about 43° to 43° 30′, 60 to 70 miles southerly from Mount Desert Island.

The eastern side of the circling movement follows so definite a track northeastward and then northward, paralleling the coast of Nova Scotia, that at least 8 per cent of all the bottles yet put out in the gulf off Cape Ann and to the northward are known to have followed this route, no doubt with others not reported for one reason or another. The large number of bottles that have stranded on that coast shows a strong tendency inshore. This Nova Scotian side of the Gulf of Maine eddy also receives water in some volume from the dead zone off Cape Sable in summer, and in some years a westerly drift past Cape Sable into the gulf of Maine persists from spring through summer.

A definite indraft into the southern side of the Bay of Fundy along its Nova Scotian shore is sufficiently demonstrated. However, this involves only the outermost edge of the Gulf of Maine eddy, the inner part of which continues northward across the mouth of the bay, a route followed by some of the bottles.

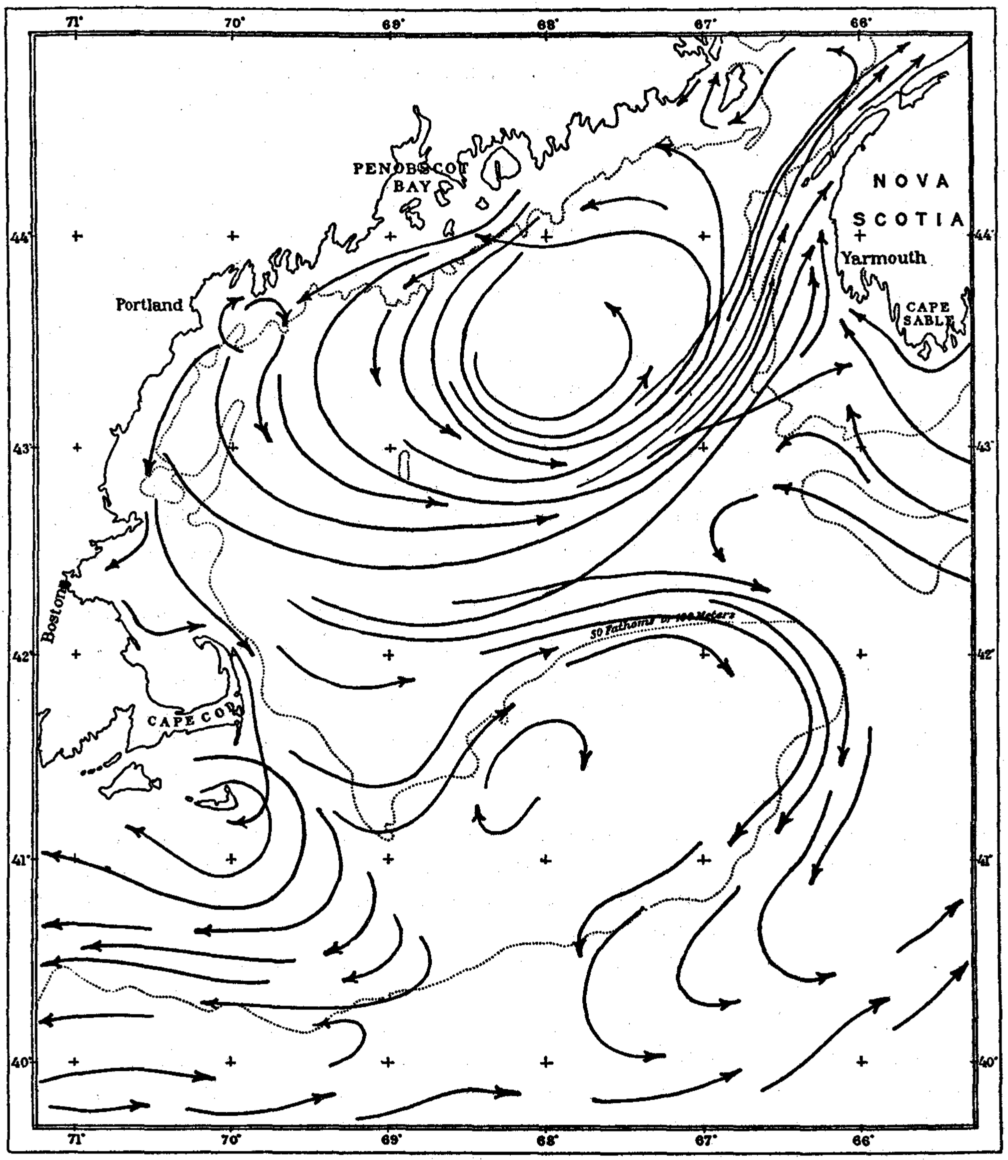

FIG. 207.—Schematic representation of the dominant nontidal circulation of the gulf, July to August

Within the Bay of Fundy the water eddies inward along the Nova Scotian side, outward along the New Brunswick side and to the southward of Grand Manan Island. However, there is some evidence that the latter forms the vortex of a second eddy of the opposite sort (clockwise) carrying water inward to the Bay of

Fundy along the Grand Manan shore of the Grand Manan Channel, with still another counter movement outward (westward) along the northern shore of the channel.

Bottle drifts identify the coastal belt between the west end of the channel and Petit Manan, some 35 miles to the westward, as to some extent a dead zone (p. 907) intervening between the coast line and the inshore edge of the gulf of Maine eddy; but the latter approaches close to the outer islands off Mount Desert.

In most summers the belt of surface water involved in the Gulf of Maine eddy is much broader in the western side of the gulf than in the eastern, with the general set more variable and its velocity smaller. As a rule a general tendency prevails for the surface water to move out from the shore all along the coast from Penobscot Bay to Cape Ann during July and August. Under these conditions a second dead area develops off the mouth of Casco Bay, with the water generally setting in the opposite direction (easterly or northeasterly) across it. A few miles farther out, however, bottle drifts and dynamic contours unite to show a decidedly definite continuation of the eddy southeastward and eastward across the basin, and so around again to Nova Scotia, dominating this side of the gulf north of an imaginary line, Cape Cod–Cape Sable.

This state is illustrated by the bottle drifts for 1922 and 1923 and by the dynamic gradients for the summer of 1914. In other summers (typified by 1913 and 1919) the westerly and southerly component of the Gulf of Maine eddy parallels the general trend of the coast line more closely as far as Cape Ann, even involving Massachusetts Bay.[98]

Somewhere in the offing of Cape Cod a division takes place between the outflow out of the gulf to the south and an easterly drift along the northern side of Georges Bank, the latter, as a whole, being the center of a clockwise system of circulation. As far as longitude 68°, or thereabouts, this easterly drift parallels the neighboring side of the Gulf of Maine eddy; but to the east of this there is a definite separation, with the water next the bank drifting around the eastern edge of the latter and so out of the gulf at considerable velocity, a fact made evident by bottle drifts as well as by dynamic evidence. Some clockwise movement is also to be expected around the shoal part of the bank; otherwise the latter is comparatively dead.

The bottle drifts, combined with current measurements, show the southerly outflow from the western side of the gulf continuing around or across Nantucket Shoals and so westward along the southern shores of New England and New York.

An easterly set has been found dominant in the entrance to Nantucket Sound, between Nantucket and Monomoy, in the only summers of record, contributing to the circling movement around Nantucket but not to the Gulf of Maine eddy. If this condition prevails as constantly as now seems probable, the local circulation of the water offers a reasonable explanation for the rather abrupt general division between the waters west and east of Cape Cod, biologic as well as hydrographic.

Bottle drifts suggest that this easterly outflow from Nantucket Sound is given off from the southern side of an anticlockwise type of circulation that involves the sound as a whole; but the tidal currents run so strongly there that more information is needed before this can be stated positively.

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[98] *Vide* the drifts of bottles from the Bay of Fundy to Cape Cod in 1919.

In some summers, if not in all, the westerly drift just mentioned involves the surface water across the whole breadth of the continental shelf in the offing of Marthas Vineyard and Nantucket. This, however, can not be regarded as a direct continuation of the outdraft from the gulf around the eastern end of Georges Bank. On the contrary, the latter probably swings offshore to join in the easterly movement of the so-called "inner edge of the Gulf Stream."

The evidences of temperature, salinity, and of dynamic gradient unite to show this "Gulf Stream" current departing from the edge of the continent as it crosses the mouth of the gulf from west to east, so that while it may be encountered within 15 miles of the 200-meter contour line at longitude 69° to 70°, it is usually at least 40 to 50 miles out at longitude 66°. Farther east, however, it again approaches the slope, at least in some summers.

Our recent cruises have afforded no evidence of any movement across Georges Bank from south to north, though the surface water not infrequently drifts northward from the edge of the continent to the west of Nantucket Shoals during the late summer.

The chief seasonal variations from the circulatory scheme just outlined result during the autumn and winter from a shift in the heavy ("low") center of anticlockwise circulation to the Eastern Channel, from a speeding up of the coastwise drift around the northern and western shores in spring, and from the brief overflow of the Nova Scotian current into the eastern side of the gulf at that same season.

As a result we find the circulation centering chiefly around the Eastern Channel in March with velocities greatest as it drifts inward along the eastern side and outward along the western side of the latter. From March to April, however, the center of circulation shifts northward across the basin; the movement slackens in the southeastern part of the area, and the coastwise drift gathers strength. Shortly thereafter, when the water of the Nova Scotian current floods into the gulf from the east, the heavy center is shifted southwestward right across the gulf. At the same time (in May) the northeast–southwest drift around the northern and western coasts attains its highest velocity and its most definitely long-shore character, and is most definitely continued southward past Cape Cod. It also involves Massachusetts Bay, not only crossing the mouth of the latter, but also skirting its coastline from north to south, and so out again past Cape Cod. Under these circumstances flotsam of any kind (buoyant fish eggs, for instance, or the larvæ hatched therefrom) that may drift from the north into the northern side of Massachusetts Bay, or that may be produced there, tends to drift out of its southern side.

This long-shore movement (involving Massachusetts Bay) may continue, little altered, into the summer; but some time between May and July the heavy center again shifts eastward, and in some years, at least, this center becomes divided into the two lows recorded for the summer of 1914—the one in the offing of the Bay of Fundy, the other in the region of the Eastern Channel. This completes the yearly cycle.

On the bottom the water moves inward along the eastern side of the Eastern Channel during the early spring, and at other times of year in pulses not yet understood, usually outward along the western side. At depths of 150 meters, or deeper, the general tendency within the basin is northward along the eastern (Nova Scotian) slope the year round, veering through west to southwest across the basin toward the offing of Massachusetts Bay; and though variations in salinity and temperature prove this drift intermittent, its stream track seems comparatively constant from season to season during its periods of activity.

The correspondence between the dominant circulation of the gulf, as established by direct evidence, and the dynamic gradient is close enough to show that the former is essentially dynamic, set in motion by the regional inequalities in density, but given its eddylike character by the confining effect of the bottom contour of Georges Bank to the south.

Deflection of the horizontal tidal oscillations by the rotation of the earth similarly tends to produce an anticlockwise movement around the basin of the gulf, and with the effect of the wind consistent with this, the several motive forces are parallel in effect.

The westerly drift of slope water along the slope of the continent is also dynamic in source, and available evidence suggests the same motive power for the "Gulf Stream" drift abreast of the gulf.

TABLES OF TEMPERATURE, SALINITY, AND DENSITY

Temperature is in degrees Centigrade, salinity in parts per mille, and density is at the temperature *in situ* but without correction for compression. The tables on page 977, summarized from Ekman's (1910) tables 2, 4, and 5, give a close enough approximation to the latter for general purposes in depths as small as those of the Gulf of Maine. For computations involving the specific volume, Smith's (1926, p. 19) simplification of Hesselberg and Sverdrup's (1915) tables are to be preferred.

STANDARDS OF ACCURACY

The old type reversing thermometers used in 1912 and 1913 were accurate only to within about ±0.15° C., but with the instruments used subsequently for the subsurface readings the probable error in temperature determination is less than 0.05° C. As the surface readings have often been taken under difficulties and by various persons, accuracy is not claimed for them beyond about ±0.3° C.

All the determinations of salinity, except some for the winter of 1925 (noted below under the respective stations), have been by titration. So far as personal and instrumental errors are concerned, the results are reliable considerably within the requirements of the International Committee for the Exploration of the Sea—probably to ±0.03 per mille of salinity. However, as Giral (1926) has recently emphasized, regional or seasonal variations in the relative proportions of the various solutes in sea water, such as are known to occur, introduce another source of error, which makes it unsafe to claim accuracy closer than about 0.05 per mille even for waters as nearly uniform in their saline content as the Gulf of Maine probably is.

The accuracy of the calculated densities depends, of course, on that of the determinations of temperature and salinity on which they are based; and while errors in these two may partially offset each other, they may, on the contrary, be cumulative. Allowing as the probable range of error 0.05° and ±0.3 per mille, the probable error for the densities will average less than ±0.04 units when the salinity has been determined by titration. In the case of hydrometer readings, the probable error of the densities will be about ±0.1 unit.

All depths, whether originally recorded in meters or fathoms, are given in meters in these tables. Tables 1, 2, and 3 show the compression of sea water as condensed from Ekman's (1910) tables 2, 4, and 5.[99]

TABLE 1.—*Correction of density for depth—water 0° and 28 in density (sp. gr. 1.028)*

Depth, meters	Increase in density	Depth, meters	Increase in density	Depth, meters	Increase in density	Depth, meters	Increase in density
10	0.05	80	0.38	200	0.97	700	3.35
20	.10	90	.43	250	1.20	800	3.83
30	.14	100	.48	300	1.42	900	4.30
40	.19	120	.57	400	1.93	1,000	4.78
50	.24	140	.67	500	2.40	1,100	5.25
60	.29	160	.76	600	2.88	1,200	5.72
70	.33	180	.87				

TABLE 2.—*Additional corrections for compression at other temperatures*

Depth	Add	Subtract																	
	−1°	1°	2°	3°	4°	5°	6°	7°	8°	9°	10°	11°	12°	13°	14°	15°	16°	17°	18°
50							0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02
100					0.01	0.01	.01	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02	.02
200	0.01	0.01	0.01	0.02	.02	.03	.03	.04	.04	.05	.05	.05	.06	.06	.07	.07	.07	.08	.08
300	.01	.01	.02	.02	.03	.04	.05	.06	.06	.07	.08	.08	.09	.09	.10	.10			
400	.01	.01	.02	.03	.04	.05	.06	.07	.08	.09	.10	.11	.12	.12	.13	.14			
500	.01	.01	.03	.04	.05	.07	.08	.09	.10	.11	.12	.14	.15	.15	.16				
600	.02	.02	.03	.05	.07	.08	.10	.11	.12	.14	.15	.16	.16	.18					
700	.02	.02	.04	.06	.08	.10	.11	.13	.14	.16	.17	.19	.20						
800	.02	.02	.05	.07	.09	.11	.13	.15	.16	.18	.20								
900	.03	.03	.05	.07	.10	.12	.14	.16	.18	.20	.22								
1,000	.03	.03	.06	.08	.11	.13	.16	.18	.20	.23	.25								
1,100	.03	.03	.06	.09	.12	.15	.17	.20	.22										
1,200	.03	.03	.07	.10	.13	.16	.19	.22	.24										

TABLE 3.—*Additional corrections for compression at other densities*

Depth	Density							
	Subtract						Add	
	22	23	24	25	26	27	29	30
100	0.01	0.01						
200	.01	.01	0.01	0.01				
300	.02	.02	.01	.01	0.01			0.01
400	.02	.02	.02	.01	.01			.01
500	.03	.02	.02	.02	.01			.01
600	.04	.03	.03	.02	.01	0.01	0.01	.01
700	.04	.04	.03	.02	.01	.01	.01	.01
800	.05	.04	.03	.03	.02	.01	.01	.02
900	.06	.05	.04	.03	.02	.01	.01	.02
1,000	.06	.05	.04	.03	.02	.01	.01	.02
1,100	.07	.06	.05	.04	.02	.01	.01	.02
1,200	.08	.06	.05	.04	.03	.01	.01	.03

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[99] Condensation of the tables entails employing an average relationship between meters and decibars. Consequently, they are accurate only to ±2 in the last decimal place. This, however, falls within the accuracy of observation and will suffice for the construction of all ordinary projections of density in water so shoal.

TABLE 4.—*Temperatures, salinities, and densities, "Grampus" stations, 1912*

Station	Date, 1912	Position	General locality	Depth	Temperature	Salinity	Density
10001	July 9	42° 30 N. 70 34 W.	Off Gloucester	0	17.78	32.07	23.05
				60	5.00	-----	-----
				64	-----	32.65	[1]25.83
10002	July 10	42 32 N. 70 23 W.	Offing of Gloucester	0	18.33	31.74	22.68
				18	9.56	-----	-----
				64	4.61	-----	-----
				73	-----	32.77	[1]25.97
				110	4.61	-----	-----
				118	-----	32.92	[1]26.09
10003	---do---	42 37 N. 70 22 W.	7½ miles off Cape Ann	0	18.89	-----	-----
				46	5.05	-----	-----
10005	July 12	42 32 N. 70 36 W.	3½ miles off Eastern Point, Gloucester	0	16.28	31.67	23.23
				49	5.17	-----	-----
				55	-----	32.57	[1]25.76
10006	July 13	42 22 N. 70 43 W.	Off Boston Harbor	0	16.11	31.96	23.45
				18	6.28	-----	-----
				46	-----	32.52	[1]25.70
				49	5.17	-----	-----
10007	July 15	42 44 N. 69 50 W.	Offing of Cape Ann	0	17.78	31.62	22.71
				46	7.39	-----	-----
				91	4.61	-----	-----
				137	4.61	33.49	26.54
				229	4.61	33.78	26.77
10008	July 16	42 45 N. 70 39 W.	North of Cape Ann	0	16.11	-----	-----
				37	-----	32.39	[1]25.70
				40	5.78	-----	-----
10009	---do---	42 49 N. 70 28 W.	Offing of Merrimac River	0	19.72	31.44	22.22
				91	4.44	32.84	26.05
10011	July 17	43 04 N. 70 20 W.	Near Isles of Shoals	0	15.00	31.92	23.64
				27	7.17	-----	-----
				46	-----	32.61	-----
				55	5.17	-----	-----
				82	4.61	-----	-----
				110	4.61	32.85	26.94
				146	-----	33.04	-----
10012b	July 23	42 53 N. 70 20 W.	Southeast from Isles of Shoals	0	13.89	31.92	23.85
				146	4.11	-----	-----
10014	July 24	43 19 N. 70 13 W.	Offing of Kennebunkport	0	13.89	31.08	23.19
				9	12.89	-----	-----
				27	6.89	-----	-----
				46	6.28	-----	-----
10015	July 25	43 37 N. 70 00 W.	Mouth of Casco Bay	0	14.44	31.26	23.23
				9	12.50	-----	-----
				18	10.78	-----	-----
				37	7.50	-----	-----
				55	6.89	32.88	25.78
10016	July 26	43 42 N. 69 42 W.	Near Seguin Island	0	13.89	31.20	23.29
				9	12.00	-----	-----
				18	10.78	-----	-----
				27	8.72	-----	-----
				37	7.44	32.14	25.13
10019	July 29	43 30 N. 69 48 W.	Offing of Casco Bay	0	13.89	31.92	23.89
				37	8.50	-----	-----
				55	7.56	-----	-----
				73	5.89	-----	-----
				91	5.67	32.97	26.01
10021	Aug. 2	43 38 N. 69 13 W.	Off Monhegan Island	0	13.05	32.43	23.21
				27	9.22	-----	-----
				55	8.17	-----	-----
				82	7.50	-----	-----
				110	7.22	32.94	25.78
10022	Aug. 7	43 26 N. 70 04 W.	Offing of Cape Elizabeth	0	16.67	-----	-----
				82	7.95	32.74	25.53

[1] Approximate only.

TABLE 4.—*Temperatures, salinities, and densities, "Grampus" stations, 1912*—Continued

Station	Date, 1912	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10023	Aug. 7	43 10 N. 69 40 W.	Platts Bank	0	17.78	32.52	23.41
				27	8.61	----------	----------
				46	7.33	----------	----------
				64	5.61	----------	----------
				82	4.89	33.30	26.36
10025	Aug. 8	43 26 N. 68 49 W.	Offing of Penobscot Bay	0	13.33	32.34	24.26
				18	9.56	----------	----------
				37	9.56	----------	----------
				55	9.11	----------	----------
				73	8.22	----------	----------
				101	7.89	33.22	25.91
10026	do	43 40 N. 69 02 W.	do	0	13.89	----------	----------
				118	7.67	33.13	25.87
10027	Aug. 14	43 26 N. 68 06 W.	South of Mount Desert Island	0	15.00	32.66	24.21
				46	7.78	----------	----------
				91	7.22	33.64	26.35
				137	6.28	----------	----------
				183	6.00	33.89	26.69
10028	do	43 26 N. 67 20 W.	East side of basin	0	15.00	32.75	24.28
				18	10.39	----------	----------
				37	8.72	----------	----------
				55	7.56	----------	----------
				101	7.39	----------	----------
				146	7.39	----------	----------
				183	7.39	----------	----------
				219	7.39	34.54	27.02
10029	do	43 26 N. 66 25 W.	German Bank	0	10.44	32.70	25.19
				18	9.83	----------	----------
				37	9.67	----------	----------
				55	9.67	----------	----------
				64	9.61	32.92	25.41
10031	Aug. 15	43 45 N. 66 55 W.	West of Lurcher Shoal	0	13.33	32.84	24.65
				37	11.50	----------	----------
				73	10.22	----------	----------
				110	8.17	----------	----------
				137	7.67	33.82	26.41
10032	Aug. 16	43 56 N. 67 58 W.	Near Mount Desert Rock	0	13.89	32.51	24.30
				165	----------	34.13	----------
10033	do	44 25 N. 67 30 W.	Off Machias, Me	0	10.6	32.68	25.09
				9	10.4	----------	----------
				27	9.83	----------	----------
				46	9.67	----------	----------
				64	9.61	32.68	25.22
10034	Aug. 17	44 50 N. 66 53 W.	Grand Manan Channel, off Campobello	0	10.00	----------	----------
				18	9.83	----------	----------
				46	9.83	----------	----------
				73	9.61	----------	----------
				101	9.56	32.68	25.23
10035	Aug. 19	44 36 N. 67 11 W.	Off Cutler, Me	0	10.56	32.57	25.00
				18	9.78	----------	----------
				37	9.78	----------	----------
				55	9.78	----------	----------
				73	9.72	----------	----------
				82	----------	32.65	25.10
10036	Aug. 20	44 16 N. 67 23 W.	Offing of Machias, Me	0	11.39	32.75	24.98
				37	9.56	----------	----------
				110	8.22	----------	----------
				146	7.61	----------	----------
				183	7.44	34.31	26.84
10037	Aug. 21	44 17 N. 68 05 W.	Off Frenchmans Bay	0	12.78	----------	----------
				18	10.50	----------	----------
				37	9.89	----------	----------
10038	do	43 51 N. 68 33 W.	Offing of Penobscot Bay	0	13.05	32.32	24.37
				37	9.95	----------	----------
				55	9.28	----------	----------
				73	9.05	----------	----------
				91	9.05	32.95	25.52
10039	Aug. 22	43 37 N. 69 01 W.	do	0	13.33	----------	----------
				37	9.44	----------	----------
				73	8.89	----------	----------
				110	8.33	----------	----------
				146	7.11	33.37	26.14

TABLE 4.—*Temperatures, salinities, and densities, "Grampus" stations, 1912*—Continued

Station	Date, 1912	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10041	Aug. 24	43 06 N. 70 12 W.	Off Isles of Shoals	0	16.11	32.07	23.54
				146	4.61		
10043	Aug. 29	42 11 N. 69 53 W.	Offing of northern Cape Cod	0	15.56	32.39	23.89
				37	10.50		
				73	8.05	33.15	25.83
				110	5.56		
				146	5.17		
				174	5.17	33.69	26.64
10044	Aug. 31	42 09 N. 70 22 W.	Massachusetts Bay, north of Cape Cod	0	14.44	32.03	23.84
				18	11.50		
				37	7.72		
				55	6.83	32.52	25.47
10045	...do	42 20 N. 70 36 W.	Mouth of Massachusetts Bay	0	16.11	31.92	23.42
				37	8.72		
				55	7.17		
				73	6.17	32.89	25.88
10046	...do	42 30 N. 70 39 W.	Massachusetts Bay off Gloucester	0	16.11	31.67	23.22
				55	6.83	32.56	25.54
10047[1]	Nov. 20	42 27 N. 70 40 W.	7 miles south (true) from Gloucester harbor mouth	0	9.17	32.57	25.21
				46	9.00	32.57	25.24
				62	9.00	32.66	25.30
10048[1]	Dec. 4	42 26 N. 70 40 W.	...do	0	8.11	32.56	25.36
				46	7.83	32.56	25.40
				70	7.83	32.61	25.45
10049[1]	Dec. 23	42 26 N. 70 40 W.	...do	0	6.95	32.74	25.66
				42	6.95	32.75	25.68
				70	6.95	32.75	26.68

[1] Stations occupied by steamer Bluewing.

TABLE 5.—*Temperatures and salinities, Massachusetts Bay to Georges Bank, April, 1913*

Date	Latitude	Longitude	Depth, meters	Temperature	Salinity
	° ′	° ′			
Apr. 11	41 47	67 18	0		33.22
14	41 37	67 18	0	6.7	33.21
			46	6.1	
15	41 52	66 45	0		33.33
15	42 03	67 01	0		33.22
15	42 08	67 12	0		33.38
15	42 14	67 28	0	6.7	
			128	5.28	
26	42 20	70 45	0		31.51
26	42 08	70 10	0		32.29
27	41 48	69 21	0		33.13
27	41 34	68 45	0		33.25
27	41 27	68 20	0	7.8	33.16
			64	6.7	33.21

TABLE 6.—*Observations by W. W. Welsh, April and May, 1913*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
1	Mar. 19	42 31 N. 70 29 W.	Off Gloucester	0	3.90	33.01	26.23
				88	3.90	33.17	26.36
2		42 35 N. 70 28 W.	...do	0	3.95	32.84	26.10
				119	3.78	33.17	26.37
4		42 51 N. 70 20 W.	Off Merrimac River	0	4.00	32.61	25.91

TABLE 6.—*Observations by W. W. Welsh, April and May, 1913*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
5	Mar. 29	43 12 N. 70 25 W.	Near Boon Island	0	3.50	32.45	25.83
				31	3.72	32.83	26.11
				64	3.83	32.99	26.23
7	Apr. 4	43 13 N. 70 24 W.	do	0	3.90	32.77	26.04
8	Apr. 5	43 10 N. 70 28 W.	do	0	3.90	32.74	26.02
				26	3.78	32.81	26.09
				51	3.90	33.04	26.26
				59	--------	33.04	26.26
9	Apr. 9	43 24 N. 70 20 W.	Off Wood Island	0	3.83	29.57	23.46
				16	3.95	30.79	24.46
				33	4.05	31.00	24.63
10	Apr. 10	43 23 N. 70 21 W.	do	0	3.44	26.74	21.30
				18	4.05	31.80	25.20
				38	4.00	32.52	25.84
11	Apr. 13	42 57 N. 70 39 W.	Near Isles of Shoals	0	4.50	31.56	25.03
				18	4.11	32.43	25.76
				37	4.05	32.66	25.94
12	Apr. 14	43 18 N. 70 26 W.	Off Cape Porpoise	0	4.56	29.13	23.09
				18	4.17	31.92	25.35
				37	3.90	32.47	25.81
13	Apr. 16	42 55 N. 70 41 W.	Near Isles of Shoals	0	5.05	30.66	24.26
				20	4.67	31.47	24.95
				55	4.05	32.52	25.83
14	Apr. 18	42 50 N. 70 41 W.	Off Merrimac River	0	5.00	30.79	24.37
				18	4.72	30.97	24.58
				44	4.05	32.47	25.79
15	Apr. 20	42 55 N. 70 45 W.	Off Hampton	0	4.67	31.11	--------
16	Apr. 22	42 55 N. 70 37 W.	Near Isles of Shoals	0	4.83	31.43	24.89
				18	4.44	31.71	25.15
				46	4.05	32.80	26.05
17	Apr. 23	42 59 N. 70 39 W.	do	0	5.11	30.93	24.47
				11	4.67	31.53	24.98
				27	4.05	32.56	25.86
18	Apr. 25	43 12 N. 70 27 W.	Near Boon Island	0	6.67	31.76	24.94
				27	4,05	32.46	25.78
				55	4.06	32.65	25.94
19	Apr. 26	43 00 N. 70 35 W.	Near Isles of Shoals	0	7.95	30.03	23.40
				27	4.00	32.45	25,78
				64	4.00	32.74	26.01
20	Apr. 29	43 02 N. 70 35 W.	do	0	7.11	31.51	24.69
				27	4.05	32.33	25.68
				64	4.00	32.72	26.00
21	May 1	42 57 N. 70 38 W.	do	0	6.56	30.66	24.08
				48	4.05	32.48	25.80
22	May 2	42 57 N. 70 40 W.	do	0	7.22	30.64	23.99
23	May 3	42 54 N. 70 42 W.	Off Hampton	0	8.11	29.92	23.31
				20	6.00	31.56	24.87
				46	4.05	32.49	25.80
24	May 5	42 54 N. 70 42 W.	do	0	9.05	29.54	22.87
				22	5.17	31.95	25.27
				48	4.11	32.50	25.81
25	May 6	42 56 N. 70 41 W.	do	0	9.78	29.60	22.80
				46	4.11	32.52	25.83
26	May 8	42 56 N. 70 41 W.	do	0	8.22	29.93	23.29
				9	7.33	--------	--------
				18	5.44	--------	--------
				44	4.17	32.30	25.65

TABLE 6.—*Observations by W. W. Welsh, April and May, 1913*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
27	May 10	42 56 N. 70 44 W.	Off Hampton	0	7.56	30.44	23.79
				20	5.56	----------	----------
				40	4.11	32.46	25.78
28	May 12	42 56 N. 70 44 W.	do	0	7.17	30.73	24.06
				18	5.67	----------	----------
				37	----------	32.18	----------
29	May 13	42 56 N. 70 44 W.	do	0	7.28	30.88	24.16
				22	5.33	----------	----------
				44	4.22	32.33	25.67
30	May 14	42 58 N. 70 35 W.	Near Isles of Shoals	0	8.11	30.50	23.75
				27	5.28	32.62	----------
				53	4.39	----------	25.88
31	May 16	42 56 N. 70 42 W.	Off Hampton	0	8.17	30.94	24.09
				48	----------	32.39	25.52
32	May 17	42 32 N. 70 44 W.	North side, Massachussetts Bay, off Bakers Island	0	8.50	30.95	24.05
				16	7.28	31.25	24.46

TABLE 7.—"*Grampus*" *stations, 1913*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′ ″					
10050[1]	Jan. 16	42 26 00 N. 70 40 00 W.	7 miles south (true) from Gloucester Harbor mouth	0	5.39	32.81	25.91
				46	5.28	32.86	25.93
				70	5.61	32.94	25.99
10051[1]	Jan. 30	42 33 00 N. 70 41 00 W.	4 miles south (true) from Gloucester Harbor mouth	0	4.72	32.56	25.79
				18	4.83	----------	----------
				35	5.39	32.82	25.93
10052[1]	...do	42 43 00 N. 70 39 00 W.	Ipswich Bay	0	4.61	32.20	25.52
				15	4.83	----------	----------
				33	5.33	32.90	25.99
10053[1]	Feb. 13	42 37 00 N. 70 30 00 W.	4 miles south, 70° east, from Cape Ann	0	2.83	32.83	26.19
				46	2.78	32.83	26.20
				82	3.11	32.84	26.18
10054[1]	Mar. 4	42 33 30 N. 70 30 00 W.	6 miles south, 32° east, from Thatchers Island	0	2.89	32.85	26.20
				46	3.05	32.96	26.27
				82	3.61	33.04	26.29
10055[1]	Apr. 3	42 33 00 N. 70 30 00 W.	do	0	4.05	32.32	25.68
				18	4.05	----------	----------
				37	4.05	----------	----------
				46	----------	33.03	26.24
				55	4.00	----------	----------
				77	3.95	33.12	26.32
10056[1]	Apr. 14	42 33 00 N. 70 39 30 W.	2 miles south from Gloucester Harbor mouth	0	5.56	31.11	24.56
				46	4.11	32.79	26.05
10057	July 8	42 06 00 N. 69 56 00 W.	Off northern Cape Cod	0	16.11	31.90	23.43
				18	10.33	31.97	24.55
				37	5.89	32.48	25.59
				55	----------	32.70	----------
				73	5.11	32.68	25.84
10058	...do	41 47 00 N. 69 10 00 W.	Offing of southern Cape Cod	0	17.22	32.40	23.53
				55	5.05	33.10	26.18
				110	4.78	33.35	26.40
				165	5.17	33.36	26.38
10059	July 9	41 06 00 N. 68 42 00 W.	Northwest part of Georges Bank	0	13.33	33.06	24.93
				27	12.61	33.07	24.99
				55	12.61	33.13	25.04
10060	...do	40 41 00 N. 69 33 00 W.	5 miles northeast of Nantucket Lightship	0	16.11	32.63	23.94
				18	14.11	32.68	24.40
				46	10.17	33.04	25.41

[1] Stations occupied by steamer Bluewing.

TABLE 7.—"*Grampus*" *stations, 1913*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′ ″					
10061	July 10	40 00 00 N. 69 29 00 W.	Continentaledge S. 8° E. Nantucket Shoals Lightship	0	20.00	33.41	23.55
				46	8.83	33.51	26.00
				91	8.50	33.62	26.14
10062	...do	40 29 00 N. 70 29 00 W.	Offing of Marthas Vineyard	0	19.44	32.86	23.42
				37	7.89	33.04	25.77
				73	6.44	33.44	26.28
10085	Aug. 4	41 39 00 N. 69 42 00 W.	Off Chatham, Cape Cod	0	17.50	32.05	23.15
				18	6.44	32.47	25.51
				48	5.83	32.56	25.66
10086	Aug. 5	42 06 00 N. 70 00 00 W.	Off northern Cape Cod. Same locality as No. 10057	0	17.11	32.09	23.30
				18	11.72	32.23	24.51
				37	6.56	32.52	25.54
				55	6.28	32.52	25.58
				73	6.22	32.52	25.59
10087	Aug. 9	42 31 00 N. 70 21 00 W.	Mouth of Massachusetts Bay, off Gloucester	0	16.67	32.09	23.41
				18	10.78	----------	----------
				37	----------	32.68	----------
				46	6.05	----------	----------
				91	5.17	32.77	25.91
				128	5.17	32.75	25.90
10088	...do	42 33 00 N. 69 33 00 W.	Basin in offing of Cape Ann	0	19.17	32.21	22.91
				46	7.72	----------	----------
				91	5.17	33.17	26.22
				183	6.28	33.87	26.64
				274	6.33	34.27	26.96
10089	Aug. 10	43 02 00 N. 69 19 00 W.	52 miles southeasterly from Cape Elizabeth	0	16.39	32.52	23.88
				18	12.05	----------	----------
				46	6.67	32.95	25.86
				91	6.67	33.26	26.10
				183	5.12	33.46	26.46
10090	...do	42 51 00 N. 68 25 00 W.	Near Cashes Ledge	0	16.11	32.56	23.91
				18	11.17	----------	----------
				46	6.78	32.92	25.83
				91	6.39	33.21	26.11
				183	6.61	33.84	26.57
10091	Aug. 11	43 24 00 N. 68 49 00 W.	Offing of Penobscot Bay	0	16.11	32.47	23.84
				18	14.50	32.57	24.22
				46	8.61	----------	----------
				91	6.72	----------	----------
				110	----------	33.40	[3] 26.20
10092	...do	43 27 00 N. 67 55 00 W.	Basin in offing of Mount Desert Rock	0	16.67	32.59	24.05
				18	11.44 9.22	----------	----------
				46	6.22	33.10	26.04
				73–82	5.56	----------	----------
				91	5.83	33.28	26.23
				183	6.11	33.91	26.70
				238	6.05	34.14	26.81
10093	Aug. 12	43 24 00 N. 67 12 00 W.	East side of basin off German Bank	0	15.83	32.61	23.95
				18	14.50	----------	----------
				37	10.67	----------	----------
				55	----------	32.95	----------
				91	5.56	----------	----------
				110	----------	33.58	[3] 26.50
				137	5.89	----------	----------
				219	5.89	34.10	26.86
10094	...do	43 25 00 N. 66 43 00 W.	Western slope of German Bank	0	8.89	32.75	25.46
				18	8.33	----------	----------
				37	----------	33.01	25.69
				46	8.33	----------	----------
				73	----------	33.24	[3] 25.88
				91	8.17	----------	----------
				113	7.17	33.62	26.32
10095	...do	43 20 00 N. 66 27 00 W.	German Bank	0	8.89	32.75	25.43
				9	8.78	----------	----------
				18	8.67	32.92	25.56
				55	8.56	32.94	25.59

[3] Approximately

TABLE 7.—"*Grampus*" *stations, 1913*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10096	Aug. 12	43° 56′ 00″ N. 66° 50′ 00″ W.	Off Lurcher Shoal	0	12.22	32.75	24.89
				18	10.95	-----	-----
				46	9.67	-----	-----
				55	-----	33.42	-----
				91	8.44	-----	-----
				110	-----	33.39	-----
				119	6.11	-----	-----
10097	Aug. 13	44° 13′ 00″ N. 67° 21′ 00″ W.	Northeast end of basin off Bay of Fundy	0	12.78	32.75	24.80
				18	11.67	-----	-----
				55	-----	32.77	-----
				91	8.00	-----	-----
				201	6.00	34.09	26.85
10098	...do.....	44° 24′ 00″ N. 67° 29′ 00″ W.	Off Machias, Me	0	10.28	32.47	25.01
				18	9.56	-----	-----
				27	-----	32.59	-----
				68	9.05	32.70	25.64
10099	...do.....	44° 08′ 00″ N. 68° 10′ 00″ W.	4 miles west of Great Duck Island, off Mount Desert.	0	12.78	32.38	24.39
				37	9.33	32.61	25.33
10100	...do.....	43° 52′ 00″ N. 67° 58′ 00″ W.	Off Mount Desert Rock	0	12.78	32.75	24.67
				18	10.11	-----	-----
				37	-----	32.95	-----
				46	8.50	-----	-----
				91	7.78	33.28	25.98
				183	6.22	33.87	26.65
10101	Aug. 14	43° 44′ 00″ N. 68° 44′ 00″ W.	Offing of Penobscot Bay	0	11.95	32.68	24.83
				18	10.11	-----	-----
				37	-----	32.92	-----
				46	9.28	-----	-----
				91	8.50	33.26	25.86
10102	...do.....	43° 34′ 00″ N. 69° 13′ 00″ W.	12 miles S. 20° E. from Monhegan Island Light	0	16.11	32.23	23.65
				18	9.56	-----	-----
				37	-----	32.66	-----
				46	8.72	-----	-----
				91	7.44	-----	-----
				128	-----	33.17	[3]26.20
				137	5.89	-----	-----
10103	...do.....	43° 32′ 00″ N. 69° 55′ 00″ W.	Off Casco Bay	0	16.11	31.83	23.35
				18	11.39	-----	-----
				37	-----	32.63	-----
				46	8.05	-----	-----
				91	6.72	32.83	25.76
10104	Aug. 15	43° 08′ 00″ N. 70° 06′ 00″ W.	Trough west of Jeffreys Ledge, off Boon Island	0	17.22	31.85	23.14
				18	9.61	-----	-----
				37	-----	32.57	-----
				46	7.33	-----	-----
				91	5.50	33.06	26.10
				146	-----	33.10	-----
				155	4.33	-----	-----
10105	...do.....	42° 48′ 00″ N. 70° 27′ 00″ W.	Trough west of Jeffreys Ledge, off Ipswich	0	17.78	32.09	23.18
				18	9.83	-----	-----
				46	6.89	-----	-----
				55	-----	32.66	-----
				91	5.33	-----	-----
				110	4.61	32.74	25.95
10106	Aug. 20	42° 29′ 00″ N. 70° 37′ 00″ W.	Mouth of Massachusetts Bay, 6 miles off Gloucester Harbor mouth.	0	16.11	32.16	23.59
				27	9.17	32.41	25.08
				69	6.72	32.57	25.56
10112	Aug. 22	40° 17′ 00″ N. 70° 57′ 00″ W.	Offing of Marthas Vineyard, 60 miles	0	20.83	34.00	24.02
				37	17.22	-----	-----
				64	15.67	34.83	25.71
				110	15.44	35.17	26.02

[3] Approximately

TABLE 8.—"*Grampus*" *stations, 1914*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10213	July 19	42° 11′ N. 69° 59′ W.	Off Northern Cape Cod	0	16.83	31.17	22.6
				20	9.06	----------	----------
				40	5.38	32.34	----------
				100	3.97	32.74	26.05
				120	----------	32.95	----------
				130	4.41	----------	----------
10214	...do....	41 49 N. 69 21 W.	Basin, off Chatham, Cape Cod	0	17.5	31.80	23.12
				20	15.75	----------	----------
				40	7.25	32.25	25.24
				100	4.22	32.92	26.13
				150	5.12	33.28	----------
				190	5.53	33.49	26.44
10215	July 20	41 19 N. 68 42 W.	Northwest part, Georges Bank	0	16.68	32.09	23.53
				20	12.24	----------	----------
				40	10.43	32.81	25.19
				70	9.62	32.88	25.38
10216	...do....	40 38 N. 68 20 W.	Southwest part, Georges Bank	0	18.60	33.10	23.87
				20	13.90	----------	----------
				40	13.04	33.58	25.30
				70	10.64	34.88	26.76
10217	July 21	40 20 N. 68 13 W.	Southwest slope, Georges Bank	0	17.3	32.74	23.82
				20	10.64	----------	----------
				40	9.15	33.60	26.01
				100	11.80	----------	----------
				150	10.63	35.23	27.04
10218	...do....	40 06 N. 68 06 W.	Continental slope, southwest of Georges Bank	0	20.48	34.42	24.37
				40	17.70	36.04	26.16
				100	14.87	35.82	26.65
				200	10.85	35.32	----------
				300	9.46	35.14	27.07
				400	----------	34.96	----------
				500	5.25	34.90	27.59
10219	...do....	40 39 N. 67 28 W.	Southern slope of Georges Bank	0	18.90	33.55	23.68
				20	17.33	----------	----------
				40	16.00	----------	----------
				90	10.28	34.65	26.65
10220	July 22	40 54 N. 66 13 W.	Continental slope, southeast of Georges Bank	0	19.98	33.82	23.94
				40	15.35	34.97	25.89
				100	11.20	35.23	26.93
				200	8.18	35.01	27.27
				300	6.90	34.94	27.41
				400	5.55	34.87	27.52
				500	5.02	34.87	27.59
10221	...do....	41 07 N. 66 20 W.	Southeast slope of Georges Bank	0	16.50	32.74	24.05
				40	16.18	34.78	25.52
				100	12.00	35.16	26.74
				160	10.78	35.25	27.03
10222	...do....	41 20 N. 66 19 W.	Southeast edge of Georges Bank	0	14.67	32.48	24.28
				90	8.98	34.18	26.50
10223	July 23	41 35 N. 66 37 W.	Southeast part of Georges Bank	0	13.33	32.59	24.57
				20	10.86	32.63	24.97
				40	8.90	32.78	25.41
				75	7.92	33.03	25.76
10224	...do....	42 03 N. 66 57 W.	Northeast part of Georges Bank	0	11.11	32.47	24.84
				30	10.76	32.54	24.92
				55	10.78	32.61	24.97
10225	...do....	42 22 N. 67 11 W.	Southeast part of basin north of Georges Bank	0	15.28	32.16	23.81
				40	10.00	33.17	25.54
				100	9.53	34.69	26.80
				150	9.33	35.05	27.12
				200	8.40	35.08	27.29
				250	7.93	35.08	27.36
10226	July 24	42 08 N. 66 14 W.	Northeast edge of Georges Bank	0	15.28	32.25	23.88
				40	12.60	32.34	24.43
				85	6.60	33.03	25.94

TABLE 8.—"*Grampus*" *stations, 1914*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10227	July 24	° ′ 42 19 N. 66 02 W.	Eastern Channel between Georges and Browns Banks	0	15.11	32.47	24.06
				40	9.30	33.04	25.55
				80	8.91	34.18	26.90
				130	8.80	34.78	27.00
				170	7.15	34.99	27.41
				220	6.95	35.03	27.47
10228	...do...	42 34 N. 65 51 W.	Browns Bank	0	14.72	32.20	23.90
				40	8.35	33.40	25.99
				85	8.50	34.25	26.63
10229	July 25	42 55 N. 65 41 W.	Northern Channel	0	11.44	32.01	24.39
				40	6.17	32.38	25.48
				100	5.96	32.92	25.93
10230	...do...	43 19 N. 65 23 W.	Offing of Cape Sable	0	10.28	31.47	24.17
				30	3.03	32.07	25.56
				50	3.14	32.34	25.77
10231	July 27	43 37 N. 64 57 W.	Profile off Shelburne, Nova Scotia	0	6.62	31.62	24.85
				30	1.81	31.98	25.59
				50	1.91 1.97	32.20	25.71
10232	July 28	43 12 N. 64 27 W.	...do...	0	15.00	31.26	32.12
				40	4.38	31.74	25.23
				100	2.88 3.45	32.88	-----
				140	5.55 5.76	33.64	26.54
10233	...do...	42 41 N. 63 58 W.	...do...	0	16.95	31.22	22.85
				40	7.34	32.96	25.80
				100	7.59	34.16	26.69
				200	7.74	-----	-----
				300	7.62	34.96	27.31
				400	5.30	34.92	27.59
				500	4.98	34.83	27.57
10243	Aug. 11	43 18 N. 65 27 W.	Offing of Cape Sable	0	13.61	31.67	23.72
				30	7.47	31.67	24.75
				55	3.51	31.98	25.45
10244	Aug. 12	43 22 N. 66 26 W.	German Bank	0	10.00	32.84	25.28
				30	9.64	32.86	25.36
				55	9.60	32.90	25.39
10245	...do...	43 49 N. 66 51 W.	West of Lurcher Shoal	0	14.44	32.52	24.20
				40	9.44	33.42	25.83
				80	8.75	33.87	26.29
				120	8.54	34.11	26.51
10246	...do...	44 15 N. 67 23 W.	Basin in offing of Machias, Me.	0	14.44	33.06	24.61
				40	8.35	33.35	25.95
				100	6.28	33.57	26.41
				150	7.58	34.05	26.68
				190	8.17	34.47	26.85
10247	...do...	44 21 N. 67 28 W.	Off Machias, Me.	0	10.44	32.52	24.96
				30	8.97	-----	-----
				60	8.88	32.84	25.47
10248	Aug. 13	43 46 N. 67 58 W.	Off Mount Desert Rock	0	13.33	32.65	24.52
				40	8.45	32.97	25.63
				100	7.18	33.51	26.24
				150	6.04	33.64	26.49
				190	8.34	34.49	26.84
10249	...do...	43 17 N. 67 40 W.	Eastern part of basin	0	17.50	31.91	23.06
				40	6.38	32.74	25.74
				100	5.31	33.06	26.12
				150	6.04	33.55	26.41
				220	5.83	33.48	26.41
10250	Aug. 14	43 39 N. 68 49 W.	Offing of Penobscot Bay	0	13.05	32.52	24.48
				40	8.59	32.92	25.57
				100	7.04	33.24	26.04
				145	6.26	33.39	26.27

TABLE 8.—"*Grampus*" *stations, 1914*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10251	Aug. 14	43 27 N. 69 39 W.	Offing of Casco Bay	0	16.56	31.92	23.28
				40	5.65	32.38	25.55
				100	4.41	32.70	25.98
				145	4.93	33.24	26.31
10252	Aug. 15	42 57 N. 70 18 W.	Off Isles of Shoals	0	16.22	31.64	23.15
				40	7.80	32.39	25.27
				90	4.64	32.56	25.80
				130	3.66	32.79	26.09
10253	Aug. 22	42 29 N. 70 18 W.	Offing of Gloucester	0	18.89	31.29	22.19
				40	6.47	32.29	25.37
				100	4.64	32.43	25.70
				140	4.49	32.50	25.77
10254	---do----	42 37 N. 69 38 W.	Basin, offing of Cape Ann	0	20.00	31.55	22.13
				40	5.75	32.43	25.57
				100	4.36		
				150	5.51	33.42	26.37
				200	6.80	34.11	26.56
				260	7.09	34.23	26.82
10255	Aug. 23	42 27 N. 68 30 W.	Central part of basin	0	19.17	31.89	22.62
				40	7.81	32.52	25.37
				100	3.95	32.81	26.07
				150	5.13	33.33	26.35
				175	6.24	33.87	26.65
10256	---do----	41 55 N. 69 25 W.	Southwest part of basin, offing of Cape Cod	0	19.56	31.80	22.46
				40	6.57	32.38	25.43
				100	4.24	32.88	26.10
				150	5.38	33.51	26.48
				180	5.68	33.64	26.54
10257	Aug. 24	41 39 N. 69 49 W.	Off Chatham, Cape Cod	0	20.00	32.05	22.54
				25	6.80	32.09	25.18
10258	Aug. 25	41 03 N. 70 51 W.	On profile running southward from Marthas Vineyard	0	19.72	32.16	22.76
				15	14.29	32.43	24.16
				30	12.09	32.52	24.66
10259	---do----	40 34 N. 70 46 W.	----do	0	21.95	33.69	23.25
				25	14.83	33.53	24.12
				55	9.67	33.60	25.98
10260	Aug. 26	40 03 N. 70 41 W.	----do	0	22.89	33.78	23.08
				40	13.67	34.09	25.53
				100	11.63	35.23	26.88
				140	11.45	35.41	27.02
10261	---do----	39 54 N, 70 43 W.	----do	0	23.50	34.11	23.14
				100	13.06	35.46	26.75
				200	11.99		
				300	9.91	35.16	27.10
				450	7.26	35.16	27.53
10262	---do----	40 02 N. 70 26 W.	----do	0	21.89	33.64	23.24
				40	13.07	33.89	25.53
				100	11.34	35.14	26.84
				180	10.35	35.26	27.11
10263	Aug. 27	41 12 N. 70 57 W.	----do	0	17.89	32.12	23.11
				17	13.30	32.45	24.38
10264	Aug. 28	42 09 N. 70 00 W.	Off northern Cape Cod	0	16.67		
				30	7.34	32.05	25.07
				80	5.65	32.48	25.63

TABLE. 9.—*Grampus stations, 1915*

		° ′					
10266	May 4	42 30 N. 70 20 W.	Offing of Gloucester	0	6.11	32.32	25.44
				50	3.55	32.68	26.01
				130	3.55	32.81	26.11
10267	May 5	42 38 N. 69 36 W.	Basin, offing of Cape Ann	0	6.10	33.03	26.00
				50	5.00	33.15	26.23
				130	4.69	33.17	26.27
				260	6.59	34.02	26.72

TABLE 9.—*Grampus stations, 1915*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10268	May 5	42 51 N. 68 43 W.	Center of gulf near Cashes Ledge	0	6.10	32.79	25.82
				50	4.78	32.81	25.98
				100	4.47	33.04	26.20
				190	5.60	33.53	26.46
10269	May 6	43 04 N. 67 56 W.	Central part of basin	0	4.40	32.50	25.78
				50	4.28	32.68	25.93
				100	4.44	32.95	26.13
				185	5.82	33.22	26.19
10270	...do...	43 14 N. 67 07 W.	East side of basin	0	3.60	31.78	25.29
				50	3.04	32.03	25.53
				100	3.90	32.86	26.12
				190	5.95	33.58	26.46
10271	May 7	43 26 N. 66 28 W.	German Bank	0	3.00	31.89	25.42
				35	3.24	31.94	25.44
				70	3.27	31.94	25.43
10272	May 10	43 52 N. 66 41 W.	Near Lurcher Shoal	0	3.90	32.05	25.47
				50	3.42	32.09	25.55
				90	3.60	32.30	25.70
10273	...do...	44 05 N. 67 32 W.	Northeast part of basin, offing of Frenchmans Bay	0	4.70	32.23	25.54
				50	4.81	32.57	25.80
				100	5.10	33.03	26.12
				150	4.98	33.28	26.34
				225	6.28	33.66	26.48
10274	...do...	44 13 N. 67 51 W.	10 miles off Petit Manan Island	0	4.20	--------	--------
				40	--------	32.20	[1]25.70
				80	3.97	32.23	25.62
10275	May 11	44 09 N. 68 09 W.	5 miles east of Great Duck Island	0	4.40	31.51	25.00
10276	May 12	43 44 N. 68 50 W.	Offing of Penobscot Bay, close to Matinicus Rock	0	5.00	31.80	25.17
				40	4.22	32.34	25.67
				80	4.22	32.43	25.75
10277	May 13	43 32 N. 69 46 W.	Offing of Casco Bay	0	7.80	29.58	23.08
				50	4.18	32.38	25.70
				95	4.15	32.45	25.76
10278	May 14	43 00 N. 70 12 W.	Trough between Isles of Shoals and Jeffreys Ledge	0	7.80	32.03	25.00
				50	4.04	32.63	25.92
				100	3.45	32.70	26.03
				175	3.70	32.94	26.19
10279	May 26	42 17 N. 70 07 W.	Mouth of Massachusetts Bay, off northern Cape Cod	0	10.00	31.89	24.55
				40	5.20	32.68	25.84
				70	3.82	32.68	25.98
10280	May 31	43 45 N. 69 32 W.	6 miles off Pemaquid Point	0	6.90	31.56	24.75
				25	5.56	31.83	25.13
10281	June 4	44 48 N. 66 55 W.	Grand Manan Channel	0	4.40	31.82	25.24
				40	4.63	31.82	25.21
				80	4.58	31.83	25.24
10282	June 10	44 25 N. 66 32 W.	Bay of Fundy Deep between Grand Manan and Brier Island.	0	6.40	31.89	25.07
				50	5.71	32.41	25.57
				100	5.20	32.83	25.96
				180	5.25	33.06	26.13
10283	...do...	44 15 N. 67 23 W.	Northeast part of basin in offing of Machias, Me.	0	5.40	31.98	25.26
				50	5.27	--------	--------
				100	5.00	32.70	25.87
				180	3.54	33.66	26.78
10284	June 11	44 09 N. 67 54 W.	12 miles off Petit Manan Island	0	5.40	32.07	25.34
				40	5.11	32.21	25.48
				80	5.14	32.45	25.67
10285	June 14	44 09 N. 68 09 W.	5 miles east of Great Duck Island, off Mount Desert Island	0	8.00	31.76	24.76
10286	...do...	43 59 N. 68 15 W.	Off Mount Desert Island	0	7.50	32.16	25.14
				40	5.44	32.30	25.51
				80	5.18	32.41	25.62

[1] Approximate.

TABLE 9.—*"Grampus" stations, 1915*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10287	June 14	43° 44′ N. 68 50 W.	Offing of Penobscot Bay close to Matinicus Rock	0	7.80	31.94	24.92
				35	5.83	32.16	25.31
				70	4.66	32.36	25.64
10288	June 19	43 28 N. 67 30 W.	Eastern side of basin	0	9.70	32.41	25.00
				50	5.60	32.50	25.65
				100	4.86	33.06	26.17
				150	5.60	33.46	26.40
				220	6.21	33.95	26.71
10289	do	43 27 N. 66 51 W.	do	0	7.80	32.25	25.16
				50	5.90	32.66	25.74
				100	5.70	33.24	26.22
				150	5.87	33.48	26.39
10290	do	43 24 N. 66 22 W.	German Bank	0	6.10	32.07	25.25
				25	5.90	32.09	25.29
				60	5.85	32.12	25.33
10291	June 23	43 29 N. 65 08 W.	Profile off Shelburne, Nova Scotia	0	8.90	30.93	23.96
				30	3.47	31.36	24.95
				75	0.96	31.92	25.58
10292	do	43 19 N. 64 59 W.	do	0	8.60	31.33	24.32
				50	0.70	31.83	25.53
				75	0.70	32.12	--------
				100	2.02	32.68	26.13
				150	4.32	--------	--------
10293	do	42 59 N. 64 43 W.	do	0	10.00	31.36	24.13
				40	1.54	31.91	25.53
				85	1.60	32.50	26.03
10294	do	42 36 N. 64 27 W.	do	0	9.70	31.06	23.95
				40	2.85	31.83	25.38
				80	2.12	32.79	26.22
				120	7.50	34.34	26.85
				170	8.28	34.67	26.99
10295	June 24	42 22 N. 64 16 W.	do	0	11.10	32.39	24.75
				80	3.63	34.27	27.22
				200	8.15	34.97	27.25
				300	7.30	34.94	27.35
				500	4.91	34.94	27.66
10296	do	42 28 N. 65 37 W.	Browns Bank	0	10.00	31.44	24.20
				40	2.80	32.29	25.76
				80	7.36	33.49	26.20
10297	June 25	42 17 N. 66 03 W.	Eastern channel between Browns and Georges Banks	0	10.00	32.56	25.06
				40	8.20	33.31	25.94
				100	8.14	34.18	26.62
				150	7.72	34.67	27.08
				225	7.20	34.92	27.35
10298	do	42 26 N. 67 45 W.	Southeast part of basin, north of Georges Bank	0	12.50	32.56	24.62
				50	5.18	32.59	25.76
				100	5.02	33.04	26.14
				150	5.68	33.48	6.41
				225	6.91	34.60	27.14
10299	June 26	42 32 N. 69 14 W.	Western side of basin in offing of Cape Ann	0	13.60	32.50	24.36
				50	6.22	33.04	26.00
				100	4.60	33.08	26.22
				210	5.67	33.82	26.68
10300	July 7	----------	Close to Race Point, Cape Cod	0	16.60	31.40	22.87
				50	6.70	32.20	25.27
10301	July 15	44 31 N. 67 24 W.	4 miles south 24° west of Libby Island at mouth of Machias Bay.	0	8.90	31.58	24.48
				60	7.16	32.03	25.09
10302	July 19	44 08 N. 68 15 W.	1 mile south of Great Duck Island, off Mount Desert Island.	0	11.60	31.83	24.24
				20	7.97	31.98	24.93
				45	7.24	32.16	25.18
10303	Aug. 4	43 46 N. 69 23 W.	3 miles west of Monhegan Island	0	11.60	31.87	24.27
				35	8.01	32.14	25.02
				75	5.96	32.41	55.54

TABLE 9.—"*Grampus*" *stations, 1915*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10304	Aug. 6-7	43° 32′ N. 67° 35′ W.	Eastern side of basin	0	11.40	32.63	24.89
				50	8.26	32.67	25.42
				100	6.22	33.12	26.06
				150	4.78	33.73	26.71
				200	6.89	34.16	27.15
10305	Aug. 18	44 08 N. 68 15 W.	1 mile south of Great Duck Island, off Mount Desert Island.	0	10.80	31.94	24.45
				25	9.37	32.05	24.77
				50	8.79	32.34	25.09
10306	Aug. 31	42 31 N. 70 19 W.	Mount of Massachusetts Bay, off Gloucester	0	16.10	31.24	22.89
				50	7.24	32.39	25.35
				100	5.97	32.50	25.60
				140	5.78	32.57	25.68
10307	...do ...	42 40 N. 69 34 W.	Basin, offing of Cape Ann	0	17.60	32.47	23.39
				50	7.77	32.81	25.61
				100	5.01	33.12	26.20
				150	5.10	33.28	26.32
				200	5.70	33.75	26.62
				235	6.36	34.23	26.92
10308	Sept. 1	42 52 N. 68 40 W.	Near Cashes Ledge	0	15.80	32.52	23.88
				40	9.02	32.59	25.25
				90	6.36	33.03	25.97
				165	5.63	33.69	26.58
10309	...do ...	43 08 N. 67 52 W.	Central part of basin	0	15.50	32.47	23.99
				50	9.44	32.66	25.23
				100	5.72	33.10	26.11
				150	5.77	33.60	26.50
				210	5.98	33.60	26.47
10310	Sept. 2	43 15 N. 67 03 W.	Eastern side of basin	0	13.30	32.41	24.42
				50	7.05	32.88	25.76
				100	5.56	33.26	26.25
				190	7.10	34.33	26.90
10311	...do ...	43 22 N. 66 17 W.	German Bank	0	9.40	32.23	24.95
				30	10.28	32.47	24.95
				65	10.10	32.56	25.05
10312	...do ...	43 14 N. 65 37 W.	9 miles off Cape Sable	0	13.30	31.49	23.64
				25	9.40	31.73	24.51
				50	7.38	32.00	25.02
10313	Sept. 6	43 28 N. 65 06 W.	11 miles off Cape Roseway, Nova Scotia	0	15.00	30.70	22.68
				20	3.38	30.73	24.47
				50	3.33	32.16	25.62
				70	2.22	32.43	25.92
10314	...do ...	43 20 N. 64 59 W.	21 miles off Cape Roseway, Nova Scotia	0	15.00	31.22	23.08
				25	7.89	31.82	24.82
				50	3.30	32.34	25.75
				75	4.95	33.01	26.12
				100	5.00	33.12	26.26
				150	5.05	33.40	26.42
10315	Sept. 7	43 49 N. 66 44 W.	Near Lurcher Shoal	0	12.20	32.88	24.93
				50	11.20	33.19	25.35
				90	10.00	33.42	25.74
10316	Sept. 11	44 32 N. 67 22 W.	2 miles south of Libby Island at the mouth of Machias Bay.	0	10.28	32.30	24.82
				60	9.95	32.43	24.97
10317	Sept. 15	44 05 N. 68 26 W.	3 miles south of Swans Island, Maine	0	11.60	32.50	24.74
				28	10.95	32.52	24.88
10318	Sept. 16	43 43 N. 69 17 W.	4 miles southeast of Monhegan Island	0	13.60	32.30	24.20
				35	[1]10.10	32.27	24.83
				70	8.61	32.56	25.28
10319	Sept. 20	43 28 N. 70 16 W.	3 miles off Wood Island, Maine	0	15.50	---------	---------
				25	10.50	31.83	24.41
				50	8.50	32.12	24.96
10320	Sept. 29	43 25 N. 70 33 W.	Massachusetts Bay, 11 miles off Gloucester Harbor mouth.	0	10.50	31.91	24.48
				35	[1]10.70	31.98	24.50
				70	7.00	32.30	25.31

[1] Approximate only.

TABLE 9.—"*Grampus*" *stations, 1915*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10321	Sept. 29	42° 10′ N. 70° 22′ W.	Mouth of Massachusetts Bay, 8 miles off Race Point, Cape Cod.	0	11.40	31.73	24.19
				20	--------	31.83	±24.19
				40	11.22	--------	--------
10322	Oct. 1	42° 04′ N. 70° 16′ W.	Close to Race Point, Cape Cod	0	13.40	31.38	23.54
				25	12.95	31.60	23.80
10323	do	42° 17′ N. 70° 07′ W.	Mouth of Massachusetts Bay, off Cape Cod	0	11.40	32.07	24.45
				40	[1]11.00	32.25	24.66
				80	6.00	33.06	26.03
10324	do	42° 31′ N. 70° 19′ W.	Mouth of Massachusetts Bay, off Gloucester	0	10.30	32.21	24.75
				40	--------	32.25	--------
				80	7.11	32.50	25.45
				120	[1]7.20	32.57	25.50
				150	6.78	32.66	25.62
10325	Oct. 4	43° 00′ N. 70° 12′ W.	Trough between Isles of Shoals and Jeffreys Ledge	0	11.60	32.21	24.53
				50	7.33	32.39	25.35
				100	6.40	32.81	25.79
				175	5.28	33.22	26.26
10326	do	43° 24′ N. 69° 53′ W.	17 miles off Cape Elizabeth	0	11.90	32.41	24.63
				50	7.61	32.90	25.70
				100	--------	32.90	--------
				145	5.39	33.48	26.45
10327	Oct. 9	44° 32′ N. 67° 20′ W.	2 miles south of Libbey Island, at the mouth of Machias Bay.	0	9.40	32.75	25.32
				30	--------	32.74	--------
				60	9.83	32.77	25.26
10328	do	44° 06′ N. 68° 14′ W.	3 miles south of Great Duck Island, off Mount Desert Island.	0	9.40	32.66	25.24
				30	--------	32.70	--------
				60	10.10	32.79	25.24
10329	do	43° 44′ N. 68° 51′ W.	Offing of Penobscot Bay, close to Matinicus Rock	0	10.00	32.47	25.00
				30	10.30	32.56	25.02
				60	8.95	32.84	25.46
10330	Oct. 18	42° 34′ N. 70° 37′ W.	2 miles eastward of Eastern Point, Gloucester	0	11.40	31.80	24.25
10331	Oct. 22	41° 19′ N. 70° 55′ W.	On profile off west end of Marthas Vineyard	0	[1]14.40	32.10	23.88
				30	14.50	32.14	23.89
10332	do	40° 51′ N. 70° 55′ W.	On profile off west end of Marthas Vineyard	0	13.90	32.32	24.16
				25	--------	32.45	--------
				50	13.10	32.92	24.78
10333	Oct. 22	40° 26′ N. 70° 56′ W.	On profile off west end of Marthas Vineyard	0	13.30	32.65	24.53
				25	13.20	32.74	24.62
				50	--------	32.97	--------
				80	11.89	33.68	25.61
10334	do	40° 09′ N. 71° 00′ W.	do	0	15.50	33.86	25.00
10335	Oct. 25	41° 26′ N. 70° 17′ W.	Vineyard Sound	0	13.00	32.09	24.16
10336	Oct. 26	41° 42′ N. 69° 53′ W.	About 3 miles off Chatham, Cape Cod	0	10.50	32.00	24.55
				25	--------	32.03	--------
				50	9.39	32.41	24.76
10337	do	42° 05′ N. 70° 18′ W.	Mouth of Massachusetts Bay, 3 miles off Race Point, Cape Cod.	0	11.10	31.89	24.36
				30	--------	31.94	--------
				60	10.39	32.14	24.68
10338	Oct. 27	42° 19′ N. 70° 30′ W.	Mouth of Massachusetts Bay, midway between Cape Cod and Gloucester.	0	11.00	31.82	24.32
				40	9.40	32.20	24.89
10339	do	42° 31′ N. 70° 36′ W.	Mouth of Massachusetts Bay, 5 miles off Gloucester Harbor mouth.	0	10.80	31.91	24.43
				35	--------	32.20	--------
				70	7.28	32.43	25.38

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[1] Approximate only.

TABLE 10.—"*Grampus*" *stations, 1916*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10340	July 19	42 32 N. 78 38 W.	Mouth of Massachusetts Bay, 3 miles off mouth of Gloucester Harbor.	0	11.95	31.18	23.66
				25	6.49	31.87	25.04
				50	5.19	32.00	25.29
10341	...do....	42 18 N. 70 27 W.	Mouth of Massachusetts Bay, midway between Gloucester and Cape Cod.	0	16.39	30.48	22.22
				25	5.08	32.03	25.33
				50	3.90	32.20	25.59
				80	3.67	----------	----------
10342	...do....	42 07 N. 70 17 W.	Mouth of Massachusetts Bay, 4 miles off Race Point, Cape Cod.	0	17.22	30.61	22.13
				30	7.73	31.58	24.65
				60	6.14	31.87	25.08
10344	July 22	42 07 N. 69 59 W.	Offing of northern Cape Cod	0	15.83	30.75	22.55
				25	4.91	32.10	25.41
				50	4.07	32.20	25.58
				80	4.19	32.38	25.71
10345	...do....	41 52 N. 69 40 W.	Offing of Chatham, Cape Cod	0	10.00	31.53	24.27
				50	4.17	32.25	25.61
				100	3.85	32.66	25.96
				150	4.06	32.86	26.10
10346	...do....	41 27 N. 69 22 W.	Offing of southern angle of Cape Cod	0	7.22	32.03	25.07
				30	6.41	32.07	25.21
				60	4.47	32.38	25.68
10347	July 23	41 06 N. 68 51 W.	Northwest side of Georges Bank	0	11.39	32.54	24.81
				30	10.91	----------	----------
				60	9.61	32.14	24.81
10348	...do....	40 49 N. 68 21 W.	West side Georges Bank	0	11.67	32.54	24.75
				25	11.34	----------	----------
				50	11.26	32.57	24.86
10349	July 24	40 15 N. 68 05 W.	Southwest slope of Georges Bank	0	17.50	32.47	23.49
				30	10.36	[1]33.86	----------
				80	7.16	[1]32.47	----------
				130	6.75	34.42	27.01
				180	6.72	34.83	27.34
10351	...do....	40 06 N. 68 57 W.	...do	0	15.56	32.47	23.93
				30	10.66	----------	----------
				80	4.82	33.42	----------
				130	5.88	34.20	26.95
				180	7.13	34.72	27.20
10352	...do....	40 00 N. 68 44 W.	Continental slope southwest of Georges Bank	0	16.95	32.47	23.61
				50	4.85	33.08	26.19
				100	7.65	34.36	26.86
				200	7.65	34.92	27.23
				300	5.75	34.87	27.51
				400	5.15	34.87	27.57
				500	4.10	34.96	27.76
10353	July 25	40 14 N. 69 08 W.	Profile running southeasterly from Marthas Vineyard	0	15.00	----------	----------
10354	...do....	40 26 N. 69 24 W.	...do	0	13.61	32.27	24.18
				30	8.71	32.63	25.33
				70	6.07	32.86	25.88
10355	...do....	40 43 N. 69 53 W.	...do	0	11.95	31.73	24.08
				30	10.97	32.14	24.57
10356	July 26	40 57 N. 70 18 W.	...do	0	16.11	31.78	23.29
				30	12.14	32.14	24.36
10357	...do....	41 11 N. 70 44 W.	...do	0	17.78	30.90	22.19
				25	14.28	31.58	23.52
10398	Aug. 29	42 10 N. 70 09 W.	Off northern Cape Cod	0	16.95	31.27	22.70
				20	7.89	31.89	24.97
				43	4.91	32.05	25.57
10399	Oct. 31	42 30 N. 70 21 W.	Mouth of Massachusetts Bay, off Gloucester	0	10.00	31.71	24.41
				30	9.18	31.91	24.69
				60	6.43	32.41	25.47
				90	5.43	32.56	25.71
				120	5.23	32.59	25.76

[1] These two water samples probably were transposed,

TABLE 10.—"*Grampus*" *stations, 1916*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10400	Nov. 1	42° 58′ N. 70° 14′ W.	Trough between Isles of Shoals and Jeffreys Ledge	0	9.72	32.03	24.71
				30	8.21	32.09	24.98
				60	7.07	32.45	25.42
				90	4.84	32.57	25.79
				130	4.41	32.81	26.03
10401	---do	42 37 N. 69 46 W.	Basin in offing of Cape Ann	0	10.56	31.98	24.54
				50	8.90	32.30	25.04
				100	4.24	32.65	25.91
				150	4.53	32.99	26.16
				200	4.99	33.53	26.53
10402	Nov. 2	43 37 N. 69 15 W.	9 miles off Monhegan Island	0	8.33	32.36	25.18
				25	8.89	32.34	25.07
				55	8.19	32.56	25.36
				85	6.59	32.78	25.74
				135	4.97	32.90	26.03
10403	Nov. 8	42 16 N. 70 12 W.	Mouth of Massachusetts Bay, off Cape Cod	0	9.17	31.87	24.66
				30	8.39	32.07	24.94
10404	---do	41 53 N. 69 37 W.	Offing of southern Cape Cod	0	10.28	32.01	24.60
				50	8.04	32.18	25.07
				100	4.85	32.88	26.06
				175	4.78	33.15	26.26
10405	Nov. 10	41 17 N. 71 03 W.	On profile running southwesterly from offing of Buzzards Bay.	0	11.95	32.05	24.31
				30	12.52	32.06	24.23
10406	Nov. 11	40 37 N. 71 19 W.	---do	0	11.67	32.23	24.52
				30	11.85	32.36	24.59
				60	9.98	32.54	25.07
10407	---do	40 03 N. 71 43 W.	---do	0	11.28	32.54	24.83
				30	11.85	32.56	24.74
				60	13.08	33.15	24.96
				90	7.72	32.88	--------
10408	---do	39 52 N. 71 47 W.	---do	0	11.39	32.59	24.86
				25	12.06	32.63	24.76
				50	14.0	33.71	25.21
				100	9.26	34.01	26.04
				180	10.26	35.00	26.93

TABLE 11.—"*Halcyon*" *stations, 1920*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
10488	Dec. 29	42° 27′ N. 70° 43′ W.	Massachusetts Bay, off Boston Harbor	0	3.89	31.82	25.29
				20	4.48	31.92	25.32
				40	5.32	--------	--------
				60	5.86	32.30	25.54
10489	---do	42 30 N. 70 17 W.	Mouth of Massachusetts Bay, off Gloucester	0	5.56	--------	--------
				40	6.94	--------	--------
				100	6.97	33.82	26.52
				150	7.00	33.84	26.53
10490	---do	42 38 N. 69 33 W.	Basin in offing of Cape Ann	0	6.11	32.76	25.76
				40	--------	--------	--------
				100	--------	33.53	26.16
				175	5.93	33.73	26.58
				250	5.14	33.85	26.76
10491	Dec. 30	42 00 N. 69 38 W.	Off northern Cape Cod	0	6.67	32.97	25.88
				40	6.82	[1]33.21	--------
				100	6.92	[1]33.01	--------
10492	---do	42 51 N. 70 46 W.	Off Merrimac River	0	4.00	30.02	23.86
				15	4.72	31.87	25.25
				30	6.80	32.60	25.58

[1] Probably transposed.

TABLE 11.—"*Halcyon*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10493	Dec. 30	42 59 N. 70 10 W.	Trough between Isles of Shoals and Jeffreys Ledge	0	5.83	32.60	25.71
				40	6.38	--------	--------
				100	6.95	32.89	25.78
				150	6.95	32.87	25.78
10494	do	43 24 N. 70 09 W.	Off Wood Island, Me	0	5.56	31.41	24.79
				40	6.23	32.65	25.69
				75	7.31	32.79	25.66
10495	Dec. 31	43 39 N. 69 36 W.	Off Seguin Island	0	5.83	32.60	25.71
				40	6.11	32.74	25.77
				75	6.11	32.77	25.80

TABLE 12—"*Halcyon*" *stations, 1921*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10496	Jan. 1	43 37 N. 68 44 W.	Offing of Penobscot Bay	0	5.56	32.31	25.50
				40	6.05	32.77	25.81
				100	6.79	32.89	25.80
				150	7.55	33.71	26.35
10497	do	44 05 N. 68 11 W.	5 miles off Great Duck Island, off Mount Desert Island, Me.	0	4.72	32.30	25.59
				40	5.53	32.54	25.68
				90	5.72	32.61	25.72
10498	Jan. 4	44 32 N. 67 13 W.	Off Machias, Me	0	5.56	--------	--------
				40	5.61	--------	--------
				70	5.61	--------	--------
10499	do	44 21 N. 66 37 W.	Fundy Deep, between Grand Manan and Brier Island	0	5.56	32.11	--------
				40	5.98	32.45	--------
				100	6.03	32.69	--------
				150	6.65	32.75	--------
				200	6.96	32.97	--------
10500	do	43 59 N. 66 52 W.	Off Lurcher Shoal	0	5.83	32.51	25.63
				40	6.17	32.51	25.60
				110	6.72	33.08	25.96
10501	do	43 48 N. 66 18 W.	Off Yarmouth sea buoy, Nova Scotia	0	3.80	31.21	24.81
				20	3.89	31.26	24.85
				40	3.86	31.29	24.87
10502	Jan. 5	44 07 N. 67 22 W.	Eastern part of basin	0	5.56	32.21	25.42
				40	6.74	32.31	25.36
				100	6.59	32.70	25.68
				150	7.22	33.37	26.12
				200	6.92	33.93	26.61
10503	Jan. 9	42 44 N. 69 55 W.	Basin in offing of Cape Ann	0	5.56	32.51	25.68
				40	5.79	32.70	25.79
				100	6.53	32.93	25.86
				150	7.57	33.75	26.36
				200	5.29	33.95	26.83
10504	Feb. 9	42 33 N. 70 39 W.	1½ miles off Eastern Point, Gloucester	0	3.33	--------	--------
				20	3.52	--------	--------
				40	3.63	--------	--------
10505	Mar. 4	42 27 N. 70 44 W.	North side, Massachusetts Bay, off Bakers Island	0	2.22	32.18	25.72
				20	2.37	--------	--------
				40	2.55	32.39	25.86
10506	do	42 52 N. 70 47 W.	Off Merrimac River	0	1.67	31.54	25.24
				25	1.81	32.08	25.66
10507	do	43 22 N. 70 08 W.	Off Cape Porpoise, Me	0	2.20	32.35	25.86
				40	3.01	32.47	25.88
				100	3.12	32.47	25.87
10508	do	43 39 N. 69 38 W.	Off Seguin Island	0	1.67	32.32	25.86
				30	2.42	32.30	25.80
				60	2.52	32.41	25.88

TABLE 12.—"*Halcyon*" *stations, 1921*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
10509	Mar. 5	43 00 N. 70 10 W.	Trough between Isles of Shoals and Jeffreys Ledge	0	3.90	32.85	25.79
				40	4.10	32.79	25.73
				100	4.32	32.86	26.07
				175	4.38	32.99	26.17
10510	...do...	42 42 N. 60 45 W.	Basin in offing of Cape Ann	0	3.60	32.49	25.85
				40	3.60	32.47	25.84
				100	4.10	32.65	25.93
				150	5.50	33.12	26.15
				175	6.50	----------	----------
				225	5.50	----------	----------
				250	4.63	33.99	26.93
10511	...do...	42 31 N. 70 18 W.	Mouth of Massachusetts Bay, off Gloucester	0	3.61	32.64	25.97
				40	3.84	32.70	26.00
				100	3.85	32.76	26.04
				150	3.86	32.70	26.00

TABLE 13.—"*Halcyon*" *stations in Massachusetts Bay, August, 1922*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′ ″					
10631	Aug. 22	42 06 00 N. 70 17 00 W.	2½ miles off Race Point, Cape Cod	0	17.80	31.20	22.52
				18	13.00	31.61	23.79
				64	6.20	32.18	25.32
10632	...do...	42 22 00 N. 70 26 00 W.	Stellwagen Bank, midway between Cape Cod and Gloucester.	0	18.00	31.21	22.37
				18	9.20	31.86	24.65
				27	7.70	31.98	24.96
				73	4.50	32.37	25.66
10633	...do...	42 32 00 N. 70 35 00 W.	Mouth of Massachusetts Bay, 4 miles off Eastern Point, Gloucester.	0	18.70	30.99	22.05
				9	18.60	31.00	22.09
				27	8.40	31.96	24.85
				55	5.40	32.23	25.46
10636	Aug. 24	42 30 00 N. 70 46 00 W.	Near Halfway Rock, off Marblehead	0	15.80	31.09	22.81
				11	11.30	31.53	24.05
				27	7.00	31.99	25.07
10637	...do...	42 26 30 N. 70 53 30 W.	Near Egg Rock, off Nahant	0	15.30	----------	----------
				18	9.80	----------	----------
10638	...do...	42 23 00 N. 70 48 00 W.	Off Boston Harbor	0	17.50	30.95	22.33
				27	8.80	31.87	24.73
10639	...do...	42 16 30 N. 70 47 00 W.	Off Minots Light	0	16.90	31.02	22.50
				15	13.90	31.20	23.30
10640	...do...	42 16 30 N. 70 35 00 W.	Off Scituate	0	18.40	31.04	22.15
				15	16.10	31.35	22.88
				51	5.60	32.25	25.45
10641	...do...	42 07 00 N. 70 38 00 W.	Off Brant Rock	0	17.80	31.04	22.32
				15	10.30	----------	----------
10642	...do...	41 56 30 N. 70 32 00 W.	Off Manomet	0	16.10	31.10	22.76
				18	13.20	----------	----------
10643	...do...	41 46 30 N. 70 26 30 W.	Cape Cod Bay, off Sandwich	0	17.80	30.97	22.26
				15	12.10	31.38	23.80
10644	...do...	41 46 00 N. 70 16 30 W.	Cape Cod Bay, off Barnstable Harbor	0	18.30	30.97	22.11
				13	17.90	----------	----------
10645	...do...	41 58 00 N. 70 21 00 W.	Midway between Provincetown and Plymouth	0	18.10	31.06	22.26
				13	17.90	----------	----------
				42	7.20	31.95	25.02

TABLE 14.—"*Halcyon*" *stations, 1923–1924*

Station	Date	Position ° ′ ″	General locality	Depth	Temperature
10646	Apr. 18, 1923	42 17 00 N. 70 29 00 W.	Mouth of Massachusetts Bay	0 37 80	2.80 1.60 .32
10647	do	41 55 00 N. 69 50 00 W.	Off Nauset, Cape Cod	0 27 64	2.80 2.00 2.20
10647	Apr. 27, 1923		Rose and Crown Shoal	0	3.30
	Aug. 5, 1923	44 11 00 N. 68 09 00 W.	Off Bakers Island, near Mount Desert	0 27 55	11.70 7.44 6.88
	Aug. 6, 1923	43 52 00 N. 67 54 00 W.	Off Mount Desert Rock	0 37 91 128 165	12.80 7.58 4.40 4.78 5.36
	Aug. 7, 1923	43 32 00 N. 70 11 00 W.	Whistle Buoy, off Cape Elizabeth	0 27 46	16.10 9.86 6.85
	do	43 18 00 N. 69 44 00 W.	25 miles off Cape Elizabeth	0 37 73 118	18.10 4.28 3.55 3.45
	Aug. 9, 1923	42 30 00 N. 70 17 30 W.	Off Gloucester	0 46 82 118 155	17.20 4.99 3.09 2.90 2.97
10652	Mar. 19, 1924	42 27 00 N. 70 36 00 W.	8 miles off Eastern Point, Gloucester	0 18 37 73	2.20 1.80 1.79 1.77
10653	June 6, 1924	42 27 00 N. 70 36 00 W.	do	0 18 37 55 73	10.60 6.25 3.58 3.13 3.13
10654	July 12, 1924	42 26 30 N. 70 37 00 W	do	0 18 37 73	16.70 6.80 4.60 3.84
10655	July 15, 1924	41 22 00 N. 69 32 00 W.	Nantucket Shoals	0 9 18 27	10.00 10.50 10.50 10.40
10656	Aug. 5, 1924	44 04 00 N. 68 07 15 W.	7 miles off Great Duck Island, Mount Desert	0 18 37 55 91	10.80 7.43 6.91 6.17 5.57
10657	Aug. 23, 1924	42 26 30 N. 70 36 15 W.	8 miles off Eastern Point, Gloucester	0 18 46 73	15.60 12.50 5.48 3.98
10664	Sept. 6, 1924	42 26 30 N. 70 37 00 W.	do	0 18 37 73	15.60 12.32 6.45 4.34
10665	Sept. 18, 1924	42 53 00 N. 70 19 30 W.	Jeffreys Ledge	0 55	14.40 7.05
10666	Sept. 24, 1924		1½ miles east-southeast (mag.) from White Island off Boothbay Harbor, Me.	0 24	11.70 10.65
10667	Sept. 29, 1924	44 04 00 N. 68 07 00 W.	7 miles off Great Duck Island, off Mount Desert	0 18 37 55 91	10.80 9.80 8.70 8.98 [illegible]

TABLE 14.—*"Halcyon" stations, 1923–1924*—Continued

Station	Date	Position	General locality	Depth	Temperature
		° ″			
10668	Oct. 3, 1924	----------------	½ mile northeast (mag.) from Little Duck Island, off Mount Desert, Me.	0	11.70
				27	10.08
10669	Oct. 15, 1924	42 26 30 N. 70 37 00 W.	8 miles south (mag.) from Eastern Point, Gloucester	0	11.70
				18	11.40
				37	10.08
				73	6.76

TABLE 15.—*Ice Patrol stations, 1919 (from Coast Guard Bulletin No. 11, 1924)*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
1	Mar. 28	42 06 N. 69 52 W.	Offing of northern Cape Cod	0	4.50	32.43	25.71
				27	3.65	32.29	25.68
				55	2.90	32.48	25.90
				77	3.75	32.61	25.93
				101	3.80	32.66	25.97
2	Mar. 29	42 23 N. 69 03 W.	do	0	4.70	32.72	25.92
				40	3.90	32.68	25.98
				80	3.05	32.66	26.03
				121	4.45	32.77	26.00
				161	5.25	33.46	26.45
3	do	42 51 N. 67 32 W.	East-central part of gulf	0	0.00	31.87	25.60
				55	3.70	32.62	25.95
				110	4.75	33.58	26.60
				165	4.75	33.84	26.80
				216	4.75	----------	----------
19	April 28	42 06 N. 69 52 W.	Offing of northern Cape Cod	0	4.70	31.29	24.79
				27	5.15	31.71	25.07
				64	3.75	31.76	25.26
				101	3.75	32.09	25.52
20	do	42 23 N. 69 03 W.	do	0	4.90	(1)	----------
				37	4.85	----------	----------
				73	4.85	----------	----------
				110	4.80	----------	----------
				146	4.35	----------	----------
21	do	42 51 N. 67 32 W.	East-central part of gulf	0	4.60	31.98	25.35
				55	3.65	32.38	25.76
				110	4.45	32.92	26.11
				165	4.40	----------	----------
				220	----------	----------	----------
22	do	43 17 N. 66 20 W.	German Bank	0	2.70	31.71	25.30
				18	2.90	31.71	25.29
				37	2.70	----------	----------
				55	2.75	31.71	25.30
35	May 29	42 06 N. 69 52 W.	Offing of northern Cape Cod	0	9.30	31.53	24.37
				35	6.05	31.80	25.05
				70	4.30	32.02	25.41
				104	4.00	32.48	25.80
				139	4.05	32.68	25.96
36	do	42 23 N. 69 03 W.	do	0	9.00	31.80	24.63
				55	4.60	33.16	26.28
				110	4.75	33.16	26.27
				165	5.40	33.48	26.44
				220	5.60	33.91	26.76
37	do	42 51 N. 67 32 W.	East-central part of basin	0	7.80	31.96	24.94
				60	4.30	32.49	25.78
				121	4.95	33.50	26.
				181	6.06	34.29	27.01
				242	6.15	----------	----------
38	May 30	43 17 N. 66 20 W.	German Bank	0	4.20	31.67	25.14
				27	4.20	31.71	25.17
				55	4.20	31.76	25.21
				82	----------	31.80	----------

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[1] Salinities for this station are omitted because irregular. They are given in U. S. Coast Guard Bulletin 11, 1924, p. 104.

TABLE 16.—"*Albatross*" *stations, 1920*

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
20044	Feb. 22	° ′ 40 07 N. 68 03 W.	Continental slope southwest of Georges Bank	0	4.44	----------	----------
				50	9.76	34.45	26.61
				100	12.39	35.18	26.67
				200	12.39	35.27	26.73
				300	10.91	35.32	27.06
				500	7.24	35.00	27.41
				1000	4.21	34.90	27.70
				1400	3.92	34.92	27.75
				1800	3.62	34.90	27.77
20045	...do....	40 18 N. 68 09 W.	Southwestern slope of Georges Bank	0	5.00	32.34	25.59
				20	4.59	32.92	26.09
				50	9.40	34.42	26.61
				100	12.35	35.34	26.79
				150	11.55	35.25	26.89
20046	...do....	40 38 N. 68 21 W.	Southwestern part of Georges Bank	0	5.00	32.34	25.59
				10	3.37	32.38	25.78
				40	4.50	32.77	25.98
				50	7.11	----------	----------
				70	8.03	----------	----------
20047	Feb. 23	41 08 N. 68 35 W.	Western part, Georges Bank	0	4.44	32.39	25.69
				20	----------	32.38	----------
				50	----------	32.47	----------
20048	...do....	41 41 N. 68 49 W.	Southwest part of basin, north of Georges Bank	0	3.33	32.47	25.86
				20	3.48	32.47	25.85
				50	3.49	32.47	25.88
				75	3.55	32.43	25.81
				100	3.54	32.49	25.86
				150	4.87	32.97	26.10
20049	...do....	42 30 N. 69 35 W.	Basin in offing of Cape Ann	0	3.33	32.52	25.93
				20	2.79	32.51	25.94
				50	2.79	32.52	25.95
				100	3.04	32.54	25.94
				150	5.66	33.40	26.37
				200	5.63	33.78	26.68
20050	Mar. 1	42 30 N. 70 18 W.	Mouth of Massachusetts Bay off Gloucester	0	2.50	32.35	25.83
				20	1.95	32.34	25.87
				40	1.89	32.36	25.89
				100	1.52	32.34	25.90
				150	1.68	32.39	25.94
20051	Mar. 1-2	42 31 N. 70 09 W.	Mouth of Massachusetts Bay	(1)	----------	----------	----------
20052	Mar. 2	42 43 N. 68 41 W.	Near Cashes Ledge	0	2.62	32.49	25.94
				20	2.24	32.52	26.00
				40	2.48	32.52	25.98
				100	2.47	32.52	25.98
				150	3.60	32.66	25.97
				200	5.24	33.44	26.43
20053	Mar. 3	42 45 N. 67 28 W.	Southeast part of basin	0	2.78	32.54	25.97
				20	2.20	32.59	26.06
				40	2.34	32.57	26.02
				100	2.28	32.61	26.05
				150	4.96	33.87	26.81
				225	5.39	34.36	27.15
20054	...do....	43 15 N. 67 45 W.	Basin in offing of Mount Desert Rock	0	2.50	32.41	25.88
				20	1.84	32.39	25.92
				40	1.84	32.39	25.92
				100	1.77	32.41	25.94
				175	5.40	33.75	26.67
				250	5.48	34.00	26.82
20055	...do....	43 42 N. 67 55 W.	19 miles off Mount Desert Rock	0	2.50	32.38	25.86
				20	1.85	32.39	25.92
				40	1.82	32.41	25.93
				100	4.39	33.16	26.30
				150	5.46	33.77	26.64
				220	5.59	33.91	26.74
20056	...do....	44 05 N. 68 08 W.	6 miles off Great Duck Island, off Mount Desert Island	0	1.15	32.21	25.82
				20	0.50	32.29	25.91
				40	0.49	32.23	25.87
				100	1.95	32.48	25.97

[1] Current station, see U. S. Bureau of Fisheries, 1921, p. 156.

TABLE 16.—"*Albatross*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
20057	Mar. 4	° ′ 43 21 N. 68 58 W.	Offing of Penobscot Bay	0	2.22	32.39	25.89
				20	1.91	32.40	25.93
				40	1.91	32.41	25.93
				75	1.89	32.41	25.93
				125	2.00	32.43	25.94
20058	...do....	43 41 N. 69 38 W.	Near Seguin Island	0	1.39	31.31	25.09
				15	0.68	32.00	25.67
				45	1.43	32.34	25.90
20059	...do....	43 25 N. 70 12 W.	6 miles off Wood Island, Me	0	1.11	32.09	25.72
				20	0.47	32.10	25.77
				40	0.61	--------	--------
				90	2.33	32.32	25.83
20060	...do....	43 02 N. 70 27 W.	10 miles off mouth of Portsmouth Harbor, N. H	0	1.39	32.28	25.86
				20	1.25	32.27	25.86
				40	1.28	32.30	25.88
				90	1.15	32.30	25.89
20061	Mar. 5	43 00 N. 70 11 W.	Trough between Isles of Shoals and Jeffreys Ledge	0	1.30	32.2	--------
				20	.85	32.17	25.80
				40	1.33	32.34	25.91
				100	1.96	32.41	25.92
				165	4.29	--------	--------
				175	4.26	32.91	26.12
20062	...do....	42 26 N. 70 43 W.	Massachusetts Bay, off Boston Harbor	0	.78	32.14	25.78
				20	.55	--------	--------
				50	.33	32.16	25.82
	Mar. 10	42 20 N. 70 40 W.	Central part, Massachusetts Bay	0	1.10	32.00	25.65
	...do....	42 17 N. 70 07 W.		0	2.20	32.43	25.92
	...do....	42 12 N. 69 06 W.		0	2.20	32.65	26.10
20063	Mar. 11	42 06 N. 68 10 W.	Southern side of basin	0	3.61	32.61	25.95
				15	3.49	32.59	25.95
				35	3.09	32.66	26.03
				95	3.05	32.63	26.02
				140	4.30	33.16	26.31
				190	4.63	34.61	27.44
20064	...do....	42 20 N. 67 13 W.	Southeast part of basin north of Georges Bank	0	3.50	32.84	26.14
				20	2.80	32.83	26.20
				40	2.73	32.84	26.26
				100	3.18	32.95	26.26
				150	4.26	33.66	26.71
				200	4.32	34.69	27.52
				265	4.24	34.76	27.60
				330	4.02	34.78	27.63
20065	...do....	41 55 N. 66 53 W.	Northeast part, Georges Bank	0	3.61	32.63	25.97
				20	2.97	32.66	26.04
				40	2.95	32.65	26.03
				80	2.73	32.69	26.20
20066	----------	41 34 N. 66 45 W.	East part, Georges Bank	0	3.33	32.57	25.94
				20	2.78	32.61	26.03
				40	2.73	32.61	26.02
				70	2.53	32.59	26.02
20067	Mar. 12	41 15 N. 66 31 W.	Southeast part, Georges Bank	0	3.05	32.68	26.06
				20	3.07	32.68	26.06
				40	2.83	32.75	26.14
				90	2.80	32.79	26.17
20068	...do....	41 02 N. 66 20 W.	Southeast slope of Georges Bank	0	3.33	32.65	26.00
				20	2.90	32.66	26.05
				40	2.92	32.66	26.05
				100	3.56	32.83	26.13
				150	4.40	33.86	26.87
				190	4.92	34.23	27.09

TABLE 16.—"*Albatross*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
20069	Mar. 12	° 40 47 N. 66 08 W.	Continental slope southeast of Georges Bank	0	3.33	----------	----------
				50	3.11	32.79	26.14
				100	7.09	33.86	26.52
				150	7.01	34.63	27.15
				200	5.92	34.67	27.32
				300	4.73	34.67	27.46
				400	4.32	34.71	27.54
				500	4.26	34.81	27.62
				1,000	3.77	34.92	27.71
20070	Mar. 13	42 03 N. 66 15 W.	Northeast edge Georges Bank	0	3.05	32.66	26.04
				20	2.78	32.67	26.06
				40	2.74	32.66	26.06
				90	2.59	32.70	26.10
20071	...do...	42 19 N. 66 02 W.	Eastern Channel between Georges and Browns Bank	0	3.33	32.81	26.13
				20	2.90	32.83	26.18
				40	3.15	32.86	26.19
				100	6.48	34.29	26.95
				150	6.85	34.42	27.00
				215	6.84	34.70	27.23
20072	...do...	42 36 N. 65 59 W.	Browns Bank	0	1.95	32.32	25.86
				20	1.88	32.34	25.87
				40	2.14	32.57	26.04
				90	3.40	33.02	26.29
20073	Mar. 17	43 30 N. 65 06 W.	On profile running southeasterly from the offing of Shelburne, Nova Scotia.	0	2.22	32.44	25.92
				20	2.10	32.43	25.93
				40	2.10	32.48	25.97
				70	2.52	32.71	26.12
20074	Mar. 19	43 18 N. 64 58 W.	...do...	0	1.39	32.09	25.70
				20	1.24	32.07	25.71
				40	1.10	32.07	25.71
				100	2.86	32.94	26.26
				150	4.68	33.69	26.70
20075	...do...	42 55 N. 64 36 W.	...do...	0	0.56	31.80	25.53
				20	0.27	31.83	25.56
				40	0.45	31.82	25.54
				90	3.76	33.21	26.40
20076	...do...	42 33 N. 64 30 W.	...do...	0	1.28	32.06	25.69
				20	0.99	32.08	25.70
				40	1.20	32.20	25.81
				100	7.39	----------	----------
				150	8.61	34.34	26.71
				200	6.20	34.70	26.91
				250	5.40	34.65	27.32
20077	Mar. 19 20	42 24 N. 64 19 W.	Continental slope in offing of Shelburne, Nova Scotia	0	1.67	32.16	25.75
				40	1.29	32.19	25.79
				100	5.82	33.78	26.52
				200	7.89	34.85	27.20
				300	6.32	34.85	27.38
				500	4.23	34.83	27.42
				1,000	3.90	34.88	27.72
20078	Mar. 20	42 58 N. 65 48 W.	Northern Channel between Browns Bank and Cape Sable.	0	1.95	32.45	25.95
				20	1.82	32.45	25.95
				40	2.12	32.43	25.93
				100	2.67	32.72	26.11
				135	4.59	33.58	26.62
20079	Mar. 22	44 21 N. 66 37 W.	Fundy Deep between Grand Manan and Brier Island	0	2.50	32.56	26.00
				20	2.14	32.54	26.01
				40	2.17	32.53	26.01
				100	2.55	32.70	26.10
				150	3.32	33.01	26.29
				200	4.29	33.31	26.44
20080	...do...	44 21 N. 67 37 W.	11 miles east of Petit Manan Island	0	1.39	32.05	25.67
				30	1.26	32.16	25.77
				60	1.43	32.25	25.83
20081	Mar. 22 23	44 08 N. 67 26 W.	Northeast part of basin, in offing of Petit Manan	0	1.95	32.32	25.85
				20	1.76	32.32	25.87
				40	1.63	32.36	25.90
				100	2.26	32.59	26.05
				150	5.07	33.67	26.63
				200	5.39	33.84	26.73

TABLE 16.—"*Albatross*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
20082	Mar. 23	43 54 N. 66 53 W.	Off Lurcher Shoal	0	2.67	32.59	26.02
				20	2.35	32.61	26.05
				50	2.52	32.72	26.13
				120	3.35	33.15	26.40
20083	do	43 41 N. 66 21 W.	Off Yarmouth, Nova Scotia	0	1.95	32.17	25.73
				20	1.54	32.18	25.77
				40	1.54	32.22	25.79
				65	2.04	32.54	26.02
20084	do	43 18 N. 66 09 W.	Off Cape Sable, Seal Island, Nova Scotia	0	2.11	32.16	25.71
				20	1.74	32.16	25.74
				50	1.81	32.23	25.80
20085	do	43 17 N. 66 33 W.	German Bank	0	2.50	------	------
				30	2.40	32.63	26.07
				70	2.43	32.63	26.06
20086	do	43 11 N. 67 12 W.	East side of basin	0	3.61	------	------
				20	3.40	33.10	26.35
				40	3.39	33.10	26.35
				100	4.29	33.63	26.69
				170	5.01	34.00	26.90
20087	Mar. 24	42 37 N. 69 27 W.	West side of basin, in offing of Cape Ann	0	3.05	32.49	25.90
				20	2.74	32.56	25.98
				40	2.74	32.54	25.96
				100	2.80	32.63	26.04
				150	5.37	33.53	26.49
				200	5.39	34.05	26.90
				250	5.06	34.22	27.05
20088	do	42 15 N. 69 54 W.	Off northern Cape Cod	0	2.50	32.36	25.85
				20	2.20	32.39	25.90
				40	2.20	32.44	25.93
				100	3.61	32.92	26.19
				180	4.97	33.58	26.58
20089	Apr. 6	42 26 N. 70 43 W.	Massachusetts Bay, off Boston Harbor	0	3.05	31.25	24.92
				10	2.39	31.26	24.97
				25	2.31	31.30	25.02
				60	1.49	32.31	25.08
20090	Apr. 9	42 30 N. 70 19 W.	Mouth of Massachusetts Bay, off Gloucester	0	3.33	32.36	25.76
				10	2.50	32.34	25.83
				30	2.42	32.34	25.83
				90	2.34	32.47	25.95
				120	2.25	32.48	25.97
20091	do	42 43 N. 70 22 W.	Jeffreys Ledge, off Cape Ann	0	3.33	31.97	25.46
				20	2.48	32.08	25.60
				60	2.50	32.45	25.91
20092	do	42 49 N. 70 37 W.	Off Merrimac River	0	3.05	31.01	24.72
				20	1.94	------	------
				40	2.45	------	------
				80	2.35	------	------
20093	do	42 57 N. 70 07 W.	Western slope of Jeffreys Ledge	0	3.05	31.92	25.45
				20	2.42	32.02	25.58
				40	2.26	32.35	25.85
				100	3.59	32.81	26.10
				160	4.29	33.10	26.25
20094	Apr. 10	43 08 N. 69 40 W.	Platts Bank	0	2.78	32.16	25.66
				20	2.34	32.17	25.76
				40	2.46	32.41	25.89
				90	2.82	32.56	25.97
20095	do	43 25 N. 70 12 W.	7 miles off Wood Island, Me.	0	3.05	30.07	23.97
				20	2.71	------	------
				40	2.25	32.50	25.97
				90	2.22	------	------
20096	do	43 40 N. 69 37 W.	Near Seguin Island	0	2.78	29.94	23.89
				20	2.02	31.60	25.28
				60	2.39	32.41	25.89

TABLE 16.—"*Albatross*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
		° ′					
20097	Apr. 10 11	43 19 N. 68 55 W.	Offing of Penobscot Bay	0	3.33	32.43	25.83
				20	2.40	32.43	25.90
				40	2.13	----	----
				100	3.46	----	----
				125	4.51	33.26	26.37
20098	Apr. 11	43 43 N. 67 55 W.	Off Mount Desert Rock	0	3.05	32.39	25.83
				20	2.33	32.44	25.92
				40	2.53	----	----
				100	3.53	----	----
				150	4.91	33.89	26.84
				210	5.28	34.22	27.05
20099	Apr. 12	44 15 N. 67 53 W.	Off Petit Manan Island	0	3.61	31.46	25.03
				20	2.23	31.90	25.50
				40	2.34	32.38	25.86
				70	2.60	32.56	25.99
20100	---do----	44 09 N. 67 26 W.	Northeast part of basin, in offing of Petit Manan Island	0	3.89	32.49	25.82
				15	3.07	32.59	25.98
				35	3.29	32.87	26.18
				95	4.50	33.55	26.60
				145	5.06	33.98	26.89
				195	5.12	34.06	26.95
				225	5.14	34.09	26.96
20101	---do----	43 53 N. 66 51 W.	Off Lurcher Shoal	0	4.28	32.89	26.10
				20	3.39	32.94	26.22
				40	3.67	33.03	26.27
				100	4.58	----	----
				140	4.71	33.78	26.77
20102	Apr. 13	43 42 N. 66 21 W.	Off Yarmouth, Nova Scotia	0	3.89	32.36	25.72
				20	3.26	----	----
				40	3.00	32.56	25.96
				60	2.83	32.56	25.97
20103	Apr. 15	43 20 N. 66 36 W.	German Bank	0	3.89	32.74	26.02
				20	3.35	32.72	26.06
				40	3.44	32.79	26.11
				90	3.46	32.79	26.11
20104	---do----	43 13 N. 65 59 W.	South of Blonde Rock, off Cape Sable	0	3.05	32.32	25.77
				15	2.80	32.34	25.80
				45	2.83	32.38	25.82
20105	---do----	42 58 N. 65 58 W.	Northern Channel, between Cape Sable and Browns Bank.	0	3.61	32.43	25.80
				20	3.61	32.42	25.80
				35	3.11	32.77	26.12
				95	3.16	32.83	26.16
				125	3.15	32.84	26.17
20106	Apr. 16	42 39 N. 66 01 W.	Browns Bank	0	3.61	32.72	26.03
				20	3.40	32.74	26.06
				40	3.35	32.73	26.06
				80	3.32	32.75	26.09
20107	---do----	42 19 N. 66 02 W.	Eastern Channel, between Browns and Georges Banks	0	3.33	32.34	25.75
				20	3.10	32.34	25.77
				40	3.21	32.56	25.94
				100	5.86	33.86	26.68
				170	7.45	34.59	27.05
				240	6.07	34.69	27.32
20108	---do----	41 57 N. 66 05 W.	Eastern edge of Georges Bank	0	4.17	32.58	25.87
				20	3.62	32.59	25.94
				50	3.08	32.60	25.98
				130	3.75	33.05	26.29
20109	---do----	41 17 N. 66 09 W.	Southeast slope of Georges Bank	0	4.17	32.65	25.92
				20	3.63	32.66	25.98
				40	3.54	32.65	25.99
				100	4.22	33.46	26.56
				150	6.47	34.52	27.13
20110	---do----	41 38 N. 66 26 W.	Eastern part of Georges Bank.	0	3.89	32.67	25.97
				20	3.54	32.70	26.02
				40	3.42	32.69	26.03
				80	3.59	32.70	26.02

TABLE 16.—"*Albatross*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
20111	Apr. 17	° 41 69 N. 66 43 W.	Eastern part of Georges Bank	0	4.17	32.60	25.88
				20	3.62	32.61	25.94
				40	3.76	32.61	25.93
				70	3.75	32.64	25.95
20112	...do....	42 22 N. 67 02 W.	Southeastern part of basin, north of Georges Bank	0	3.61	32.54	25.89
				20	3.39	32.52	25.90
				40	3.26	32.56	25.94
				100	3.15	32.86	26.18
				175	5.22	34.56	27.33
				225	4.66	34.70	27.50
				290	4.71	34.70	27.50
20113	...do....	42 53 N. 67 37 W.	Central part of basin	0	3.33	32.50	25.88
				20	2.88	32.47	25.90
				40	2.93	32.48	25.90
				100	4.32	33.51	26.59
				165	5.16	34.23	27.07
				230	5.16	34.43	27.23
20114	...do....	42 41 N. 68 40 W.	Near Cashes Ledge	0	3.33	32.41	25.81
				20	3.28	32.45	25.85
				40	2.91	32.43	25.87
				100	4.12	33.19	26.36
				175	4.96	34.18	27.05
20115	Apr. 18	42 37 N. 69 33 W.	Western side of basin, in offing of Cape Ann	0	3.61	32.45	25.81
				20	3.33	32.48	25.87
				40	3.20	32.47	25.87
				100	3.02	32.80	26.15
				150	5.38	33.69	26.62
				200	6.36	33.93	26.68
				290	4.92	34.34	27.19
20116	...do....	42 03 N. 69 38 W.	Off Cape Cod Highlands	0	3.61	32.14	25.57
				20	3.60	32.14	25.57
				40	3.13	32.16	25.63
				100	3.42	32.79	26.11
				195	4.25	33.91	26.91
20117	...do....	42 09 N. 69 58 W.	Off northern Cape Cod	0	3.61	31.87	25.36
				20	3.13	31.86	25.40
				40	3.00	32.08	25.58
				85	3.24	32.78	26.12
20118	Apr. 20	41 51 N. 70 18 W.	Cape Cod Bay	0	4.44	31.55	25.02
				15	3.76	31.52	25.07
				28	3.46	31.50	25.08
20119	...do....	42 18 N. 70 28 W.	Massachusetts Bay, midway between Cape Cod and Gloucester.	0	3.61	31.43	25.01
				20	2.87	31.56	25.18
				40	1.58	32.03	25.65
				90	1.78	32.29	25.84
20120	May 4	42 27 N. 70 25 W.	Mouth of Massachusetts Bay, off Gloucester	0	6.39	29.16	22.93
				5	6.12	29.11	22.93
				10	5.88	29.17	23.00
				15	5.90	29.18	23.00
				20	4.67	29.55	23.42
				30	4.52	31.13	24.69
				50	3.96	31.36	24.93
				70	2.72	----------	----------
20121	...do....	42 27 N. 70 25 W.	....do	0	5.56	29.08	22.96
				30	3.92	30.99	24.62
				60	2.39	32.24	25.76
20122	May 7-8	42 49 N. 70 37 W.	Off Merrimac River	0	7.22	28.26	22.18
				5	6.54	28.45	22.35
				10	5.61	30.59	24.14
				15	4.42	31.17	24.72
				20	4.18	31.24	24.81
				35	3.10	----------	----------
				50	3.13	32.17	25.63
				65	2.48	32.25	25.76
				85	2.30	32.38	25.86
20123	May 16	42 28 N. 70 43 W.	Massachusetts Bay, off Boston Harbor	0	8.89	29.94	23.20
				20	4.83	30.72	24.30
				55	2.35	32.18	25.73

TABLE 16.—"*Albatross*" *stations, 1920*—Continued

Station	Date	Position	General locality	Depth	Temperature	Salinity	Density
20124	May 16	42° 28′ N. 70 18 W.	Mouth of Massachusetts Bay, off Gloucester	0	9.72	29.87	23.02
				20	5.12	30.77	24.33
				40	2.89	32.07	25.58
				100	2.65	32.45	25.90
20125	do	42 00 N. 69 41 W.	Off Cape Cod highlands	0	9.17	30.25	23.40
				20	5.73	32.07	25.30
				40	3.78	32.34	25.71
				100	3.58	32.92	26.20
				140	4.04	33.21	26.38
20126	May 17	41 39 N. 69 22 W.	Offing of southern Cape Cod	0	8.33	31.53	24.52
				20	5.90	32.16	25.35
				40	4.30	32.54	25.82
				100	3.60	32.81	26.10
				160	4.10	33.49	26.60
20127	do	41 20 N. 69 06 W.	Basin east of Nantucket	0	7.22	31.89	24.93
				20	5.75	32.24	25.46
				40	4.10	--------	--------
				100	3.80	32.88	26.14
				145	3.80	32.98	26.24
20128	do	40 34 N. 68 53 W.	33 miles eastward from Nantucket Shoals Lightship	0	7.78	32.48	25.35
				20	5.55	32.47	25.63
				40	5.40	32.47	25.66
				70	5.04	32.50	25.71
20129	do	40 05 N. 69 04 W.	Continental edge off Nantucket Shoals	0	7.78	32.61	25.45
				10	7.56	32.61	25.48
				30	5.30	32.74	25.87
				90	7.32	33.84	26.48
				160	8.24	34.72	26.96

TABLE 17.—"*Fish Hawk*" *stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*

[For key chart, see Bigelow, 1926, fig. 9]

Station	Position	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
2	42° 12 00″ N. 70 23 30 W.	Mouth of the bay, 10 miles off Race Point, Cape Cod.	2	Dec. 11, 1924	0	6.75	--------	--------
					33	6.79	--------	--------
					66	6.85	--------	--------
			3	Dec. 16, 1924	0	5.95	--------	--------
					28	5.97	--------	--------
					56	5.95	--------	--------
			4	Dec. 22, 1924	0	4.90	--------	--------
					33	4.62	--------	--------
					64	4.90	--------	--------
			5	Jan. 6, 1925	0	4.05	--------	--------
					32	4.01	--------	--------
					64	4.15	--------	--------
			6	Feb. 6, 1925	0	2.00	[1]32.87	26.29
					32	1.81	[1]32.90	26.32
					63	3.10	[1]32.83	26.18
			7	Feb. 24, 1925	0	2.10	[1]32.75	26.19
					32	1.83	[1]32.71	26.28
					64	1.90	[1]33.07	26.46
			8	Mar. 10, 1925	0	2.40	[1]32.94	26.32
					33	2.14	[1]32.98	26.38
					65	2.05	[1]33.12	26.50
3	42 09 30 N. 70 19 30 W.	Mouth of the bay, 7 miles off Race Point, Cape Cod.	2	Dec. 11, 1924	0	6.50	--------	--------
					13	7.50	--------	--------
					26	6.55	--------	--------
			11	Apr. 7, 1925	0	4.10	--------	--------
					30	4.08	--------	--------
					60	3.40	--------	--------
			12	Apr. 22, 1925	0	5.50	[1]31.71	25.08
					17	5.49	[1]31.62	24.97
					33	3.79	[1]32.50	25.83
			13	May 21, 1925	0	8.50	[1]31.47	24.43
					15	8.14	[1]31.36	24.42
					30	5.15	[1]31.59	24.94
			14	June 17, 1925	0	12.13	32.38	24.57
					10	12.05	32.38	24.56
					20	9.23	32.52	25.03
					30	5.06	33.17	26.13

[1] From hydrometer reading.

TABLE 17.—"*Fish Hawk*" *stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
4	° ′ ″ 42 05 30 N. 70 17 00 W.	3 miles off Race Point, Cape Cod	2	Dec. 11, 1924	0	6.70	--------	--------
					31	6.42	--------	--------
					62	6.90	--------	--------
			5	Jan. 6, 1925	0	3.65	--------	--------
					29	3.87	--------	--------
					58	4.05	--------	--------
			6	Feb. 6, 1925	0	0.60	[1]32.51	26.09
					30	0.60	[1]32.61	26.17
					60	1.00	[1]32.74	26.25
			11	Apr. 7, 1925	0	4.40	--------	--------
					30	4.20	--------	--------
					60	3.58	--------	--------
			12	Apr. 22, 1925	0	6.00	[1]31.87	25.11
					27	5.20	[1]31.76	25.14
					55	4.18	[1]32.32	25.68
			13	May 21, 1925	0	9.80	[1]31.58	24.33
					30	3.83	[1]32.36	25.73
					60	3.20	[1]32.35	25.77
			14	June 17, 1925	0	14.79	32.30	23.95
					10	14.35	32.30	24.05
					20	7.47	32.81	25.65
					40	3.75	33.24	26.43
					60	3.74	33.24	26.43
5	42 00 45 N. 70 11 50 W.	Close to Wood End, Cape Cod	2	Dec. 11, 1924	0	5.30	--------	--------
					20	5.43	--------	--------
					40	5.30	--------	--------
			3	Dec. 16, 1924	0	4.60	--------	--------
					21	4.93	--------	--------
					42	4.25	--------	--------
			5	Jan. 6, 1925	0	2.80	--------	--------
					19	2.85	--------	--------
					39	2.80	--------	--------
			6	Feb. 6, 1925	0	0.60	[1]32.43	--------
					20	0.14	--------	--------
					39	0.10	--------	--------
			7	Feb. 24, 1925	0	2.30	[1]32.29	25.94
					22	1.88	[1]32.61	26.09
					43	2.34	[1]32.99	26.37
6	41 55 39 N. 70 09 30 W.	Cape Cod Bay, off Wellfleet	3	Dec. 11, 1924	0	5.20	--------	--------
					13	5.34	--------	--------
					26	4.70	--------	--------
			4	Dec. 22, 1924	0	4.90	--------	--------
					14	4.55	--------	--------
					28	4.80	--------	--------
			5	Jan. 6, 1925	0	2.45	--------	--------
					12	2.48	--------	--------
					24	2.70	--------	--------
			6	Feb. 6, 1925	0	0.20	[1]32.25	25.90
					18	0.81	[1]32.29	25.89
					16	0.00	[1]32.57	26.16
			11	Apr. 8, 1925	0	4.90	--------	--------
					13	4.86	--------	--------
					26	5.14	--------	--------
			12	Apr. 22, 1925	0	6.80	[1]32.01	25.12
					15	4.63	--------	--------
					30	3.79	[1]32.21	25.62
			13	May 20, 1925	0	10.20	[1]31.63	24.31
					15	9.95	[1]31.65	24.36
					30	9.88	[1]31.78	24.48
6A	41 56 00 N. 70 18 30 W.	Central part, Cape Cod Bay	6	Feb. 6, 1925	0	−0.60	[1]32.62	26.21
					17	−1.55	[1]32.45	26.12
					34	−0.40	[1]32.74	26.32
			11	Apr. 8, 1925	0	4.75	[1]31.86	25.34
					22	4.40	--------	--------
					45	2.86	[1]32.30	25.77
			12	Apr. 22, 1925	0	6.60	[1]31.76	24.94
					17	5.77	[1]31.43	(?)
					35	4.98	[1]31.71	25.09
			13	May 20, 1925	0	10.20	[1]31.73	24.39
					17	--------	[1]31.44	--------
					34	4.62	[1]31.89	25.12
			14	June 16, 1925	0	15.01	31.80	23.53
					10	14.91	32.01	23.71
					20	8.47	32.38	25.71
					34	4.66	32.45	25.18

[1] From hydrometer reading.

TABLE 17.—*"Fish Hawk" stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
7	41° 49′ 30″ N. 70° 11′ 15″ W.	South side, Cape Cod Bay	2	Dec. 9, 1924	0	6.30	--------	--------
					6	6.32	--------	--------
					12	6.30	--------	--------
			3	Dec. 11, 1924	0	4.25	--------	--------
					7	4.43	--------	--------
					14	4.35	--------	--------
			5	Jan. 7, 1925	0	0.30	--------	--------
					6	0.37	--------	--------
					13	0.25	--------	--------
			6	Feb. 6, 1925	0	−0.70	[1]32.35	26.02
					6	−0.41	[1]32.47	26.11
					11	−0.60	[1]32.66	26.23
			7	Feb. 24, 1925	0	1.60	[1]32.25	25.82
					6	1.48	[1]32.35	25.91
					12	1.39	[1]32.34	25.90
			11	Apr. 8, 1925	0	5.40	--------	--------
					6	5.24	--------	--------
					12	5.26	--------	--------
			12	Apr. 23, 1925	0	6.30	--------	--------
					6	--------	--------	--------
					12	6.48	--------	--------
			13	May 20, 1925	0	11.00	--------	--------
					6	10.96	--------	--------
					12	10.92	--------	--------
			14	June 16, 1925	0	15.23	32.23	23.81
					10	15.20	32.38	23.92
8	41° 49′ 00″ N. 70° 24′ 30″ W.	Cape Cod Bay, off Sandwich	1	Dec. 3, 1924	0	6.85	--------	--------
					23	6.80	--------	--------
9	41° 53′ 15″ N. 70° 27′ 00″ W.	West side, Cape Cod Bay	1	Dec. 3, 1924	0	6.93	--------	--------
					33	6.40	--------	--------
			2	Dec. 9, 1924	0	6.30	--------	--------
					14	6.73	--------	--------
					28	6.10	--------	--------
			3	Dec. 16, 1924	0	4.90	--------	--------
					17	4.93	--------	--------
					34	4.40	--------	--------
			4	Dec. 22, 1924	0	4.80	--------	--------
					17	4.83	--------	--------
					34	4.80	--------	--------
			5	Jan. 7, 1925	0	2.15	--------	--------
					16	2.20	--------	--------
					32	2.15	--------	--------
			6	Feb. 6, 1925	0	1.90	[1]32.70	26.21
					15	0.59	[1]32.78	26.34
					29	0.70	[1]33.19	26.63
10	41° 58′ 00″ N. 70° 30′ 15″ W.	Off Manomet, Plymouth, Mass.	1	Dec. 3, 1924	0	6.74	--------	--------
					33	6.80	--------	--------
			2	Dec. 9, 1924	0	6.90	--------	--------
					18	6.93	--------	--------
					36	7.10	--------	--------
			3	Dec. 17, 1924	0	5.40	--------	--------
					18	5.47	--------	--------
					36	5.90	--------	--------
			4	Dec. 22, 1924	0	4.60	--------	--------
					19	4.63	--------	--------
					37	4.80	--------	--------
			5	Jan. 7, 1925	0	2.25	--------	--------
					19	2.47	--------	--------
					37	2.15	--------	--------
			6	Feb. 7, 1925	0	1.00	[1]32.77	26.35
					18	0.87	[1]32.62	26.21
					35	0.80	[1]32.79	26.30
			7	Feb. 28, 1925	0	1.10	--------	--------
					19	1.43	--------	--------
					36	1.40	--------	--------
			8	Mar. 10, 1925	0	2.00	[1]32.66	26.12
					17	1.63	[1]32.61	26.11
					33	2.17	[1]32.52	26.00
			11	Apr. 8, 1925	0	4.10	[1]31.18	24.77
					20	4.59	--------	--------
					40	2.46	[1]32.26	25.76
			12	Apr. 23, 1925	0	5.60	[1]31.60	24.93
					22	5.54	--------	--------
					44	4.87	[1]31.66	25.06

[1] From hydrometer reading.

TABLE 17.—"*Fish Hawk" stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position ° ′ ″	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
10	41 58 00 N. 70 30 15 W.	Off Manomet, Plymouth, Mass.	13	May 20, 1925	0	9.00	[1]31.76	24.62
					17	5.14	[1]31.56	24.96
					34	3.99	[1]31.92	25.37
			14	June 16, 1925	0	14.43	32.16	23.93
					10	12.83	32.23	24.31
					20	5.98	32.81	25.84
					38	5.69	32.95	25.99
11	41 59 30 N. 70 31 30 W.	Off Plymouth Harbor	1	Dec. 3, 1924	0	6.84	--------	--------
					35	6.85	--------	--------
			2	Dec. 9, 1924	0	6.80	--------	--------
					18	6.82	--------	--------
					36	6.70	--------	--------
			3	Dec. 17, 1924	0	5.40	--------	--------
					18	5.93	--------	--------
					36	6.10	--------	--------
			4	Dec. 23, 1924	0	4.50	--------	--------
					18	4.63	--------	--------
					35	4.60	--------	--------
			5	Jan. 7, 1925	0	2.00	--------	--------
					18	2.00	--------	--------
					35	1.15	--------	--------
11A	42 00 00 N. 70 32 15 W.	do	6	Feb. 7, 1925	0	1.10	[1]32.67	26.19
					18	1.01	[1]32.97	26.44
					36	1.20	[1]32.92	26.39
12	42 01 15 N. 70 33 00 W.	do	1	Dec. 3, 1924	0	6.51	--------	--------
					27	6.40	--------	--------
			2	Dec. 9, 1924	0	6.90	--------	--------
					14	6.42	--------	--------
			3	Dec. 17, 1924	0	5.60	--------	--------
					13	5.62	--------	--------
					26	6.05	--------	--------
			4	Dec. 23, 1924	0	--------	--------	--------
					16	4.63	--------	--------
					31	3.50	--------	--------
			5	Jan. 7, 1925	0	2.15	--------	--------
					13	1.67	--------	--------
					26	1.55	--------	--------
13	42 03 00 N. 70 34 30 W.	Off Gurnet Point	1	Dec. 3, 1924	0	5.83	--------	--------
					20	5.80	--------	--------
			2	Dec. 9, 1924	0	5.85	--------	--------
					17	5.73	--------	--------
					34	5.50	--------	--------
			3	Dec. 17, 1924	0	5.80	--------	--------
					12	5.83	--------	--------
					24	5.05	--------	--------
			4	Dec. 23, 1924	0	2.50	--------	--------
					13	4.54	--------	--------
					25	4.50	--------	--------
			5	Jan. 7, 1925	0	2.00	--------	--------
					13	1.90	--------	--------
					25	1.90	--------	--------
13A	42 02 30 N. 70 34 00 W.	do	6	Feb. 7, 1925	0	1.20	[1]32.81	26.30
					16	1.10	[1]32.94	26.41
					32	1.10	[1]33.04	26.50
			7	Feb. 28, 1925	0	1.21	--------	--------
					15	1.13	--------	--------
					30	1.21	--------	--------
			8	Mar. 10, 1925	0	1.70	--------	--------
					13	1.64	--------	--------
					25	1.45	--------	--------
			11	Apr. 8, 1925	0	5.40	--------	--------
					12	4.63	--------	--------
					24	3.81	--------	--------
14	42 05 00 N. 70 35 00 W.	Off Green Habor	1	Dec. 3, 1924	0	5.13	--------	--------
					18	4.90	--------	--------
			2	Dec. 9, 1924	0	5.90	--------	--------
					13	5.87	--------	--------
					26	5.80	--------	--------
				Dec. 17, 1924	0	4.60	--------	--------
					11	4.51	--------	--------
					22	4.20	--------	--------

[1] From hydrometer reading.

TABLE 17.—"*Fish Hawk" stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position ° ′ ″	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
14	42 05 00 N. 70 35 00 W.	Off Green Harbor	4	Dec. 23, 1924	0	4.50	--------	--------
					8	2.56	--------	--------
					16	3.90	--------	--------
			5	Jan. 7, 1925	0	2.15	--------	--------
					13	2.23	--------	--------
					25	2.05	--------	--------
			6	Feb. 7, 1925	0	−0.10	[1]32.72	26.29
					11	−0.20	[1]32.98	--------
					22	0.20	[1]32.78	26.33
			11	Apr. 8, 1925	0	5.10	--------	--------
					10	5.22	--------	--------
					20	4.65	--------	--------
			12	Apr. 23, 1925	0	5.30	31.9	--------
					10	5.10	31.7	--------
					20	4.60	31.7	--------
			13	May 20, 1925	0	8.80	[1]31.85	24.49
					10	8.84	--------	--------
					20	4.69	[1]31.87	25.20
			14	June 16, 1925	0	15.21	32.09	23.70
					10	10.66	32.38	24.79
					20	7.56	32.66	25.52
15	42 09 30 N. 70 38 15 W.	Off Marshfield	1	Dec. 3, 1924	0	4.82	--------	--------
					20	4.80	--------	--------
			2	Dec. 9, 1924	0	4.95	--------	--------
					12	4.93	--------	--------
					24	4.90	--------	--------
			3	Dec. 17, 1924	0	4.25	--------	--------
					10	4.25	--------	--------
					20	4.25	--------	--------
			4	Dec. 23, 1924	0	3.50	--------	--------
					12	4.54	--------	--------
					24	3.00	--------	--------
			5	Jan. 7, 1925	0	2.05	--------	--------
					10	2.47	--------	--------
					20	2.95	--------	--------
			6	Feb. 7, 1925	0	0.00	[1]32.67	26.25
					12	−0.50	[1]32.63	26.24
					23	2.03	[1]32.91	26.33
			7	Feb. 28, 1925	0	1.21	--------	--------
					12	1.21	--------	--------
					22	1.30	--------	--------
			8	Mar. 10, 1925	0	2.00	[1]32.43	25.94
					11	1.67	[1]32.47	26.00
					21	1.95	[1]32.58	26.07
16	42 14 00 N. 70 41 00 W.	Off Scituate	1	Dec. 3, 1924	0	5.62	--------	--------
					24	5.80	--------	--------
			2	Dec. 9, 1924	0	5.65	--------	--------
					12	5.62	--------	--------
					24	6.10	--------	--------
			3	Dec. 17, 1924	0	3.80	--------	--------
					13	4.50	--------	--------
					26	4.80	--------	--------
			4	Dec. 23, 1924	0	4.50	--------	--------
					13	4.54	--------	--------
					25	4.50	--------	--------
			5	Jan. 7, 1925	0	2.70	--------	--------
					10	2.70	--------	--------
					20	2.70	--------	--------
			6	Feb. 7, 1925	0	0.00	[1]32.54	26.14
					12	−0.10	[1]32.92	26.45
					24	0.50	[1]32.95	26.45
			11	Apr. 8, 1925	0	5.05	--------	--------
					15	4.93	--------	--------
					30	3.52	--------	--------
			12	Apr. 23, 1925	0	5.70	[1]31.55	24.87
					12	5.10	[1]31.62	25.02
					24	4.58	[1]31.66	25.11
			14	June 16, 1925	0	15.17	32.09	23.70
					10	15.14	32.09	23.72
					26	6.76	32.66	25.62
17	42 18 15 N. 70 44 00 W.	Off Minots Light	1	Dec. 3, 1924	0	6.83	--------	--------
					38	6.90	--------	--------
			2	Dec. 9, 1924	0	6.50	--------	--------
					18	6.42	--------	--------
					36	6.50	--------	--------
			3	Dec. 16, 1924	0	5.15	--------	--------
					16	5.34	--------	--------
					32	5.20	--------	--------

[1] From hydrometer reading.

TABLE 17.—"*Fish Hawk*" *stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
17	° ′ ″ 42 18 15 N. 70 44 00 W.	Off Minots Light	4	Dec. 22, 1924	0	4.90	--------	--------
					19	4.53	--------	--------
					35	4.50	--------	--------
			12	Apr. 23, 1925	0	5.60	[1]31.60	24.95
					17	5.13	[1]31.70	25.09
					35	4.60	[1]31.60	25.02
			13	May 20, 1925	0	8.70	[1]31.60	24.53
					16	5.00	[1]31.96	25.30
					32	3.68	[1]32.20	25.46
			14	June 16, 1925	0	15.00	32.23	23.86
					10	14.32	32.16	23.94
					20	7.27	32.66	25.56
					37	4.65	32.95	26.11
18	42 15 30 N. 70 32 30 W.	Central part of Massachusetts Bay	3	Dec. 16, 1924	0	5.40	--------	--------
					30	5.49	--------	--------
					60	5.45	--------	--------
			4	Dec. 22, 1924	0	4.50	--------	--------
					32	5.03	--------	--------
					64	4.50	--------	--------
			5	Jan. 6, 1925	0	3.50	--------	--------
					32	3.57	--------	--------
					63	4.35	--------	--------
18A	42 17 00 N. 70 30 30 W.	do	6	Feb. 6, 1925	0	2.00	[1]33.01	26.40
					34	1.85	[1]33.08	26.48
					68	2.00	--------	--------
			7	Feb. 24, 1925	0	2.00	[1]33.14	26.51
					35	1.70	[1]32.51	26.12
					70	2.20	[1]33.10	26.45
			8	Mar. 10, 1925	0	1.90	[1]32.90	26.32
					38	1.88	[1]32.91	26.33
					76	1.85	[1]33.01	26.41
			12	Apr. 23, 1925	0	6.40	[1]31.86	25.05
					35	4.00	[1]32.00	25.38
					70	2.88	[1]32.48	25.92
			13	May 20, 1925	0	8.15	[1]31.50	24.53
					40	3.71	[1]32.29	25.68
					80	3.08	[1]32.38	25.81
			14	June 16, 1925	0	15.22	[2]32.33	--------
					10	13.88	[2]32.16	--------
					20	6.11	32.95	25.94
					40	3.55	33.39	26.57
					79	3.23	33.24	26.48
19	42 22 00 N. 70 38 00 W.	Off Boston Harbor	5	Jan. 6, 1925	0	3.95	--------	--------
					29	3.97	--------	--------
					58	4.10	--------	--------
			6	Feb. 6, 1925	0	2.60	[1]33.13	26.44
					35	2.06	[1]33.26	26.60
					70	2.60	[1]33.18	26.66
20	42 44 00 N. 70 36 45 W.	Ipswich Bay	9	Mar. 12, 1925	0	3.50	[1]31.47	25.07
					32	2.60	[1]32.94	26.31
					64	2.70	[1]33.11	26.42
21	42 46 00 N. 70 40 00 W	do	9	do	0	3.60	[1]30.71	24.44
					21	2.81	[1]33.08	26.39
					41	2.45	[1]33.19	26.50
			10	Mar. 25, 1925	0	3.80	--------	--------
					32	2.71	--------	--------
					64	2.82	--------	--------
			11	Apr. 7–8, 1925	0	4.90	[1]28.75	22.76
					20	2.62	--------	--------
					39	2.61	[1]31.80	25.38
22	42 47 45 N. 70 43 30 W.	do	9	Mar. 12, 1925	0	3.80	[1]32.41	25.77
					15	2.46	[1]32.86	26.25
					30	2.44	[1]32.94	26.31
			10	Mar. 25, 1925	0	3.60	--------	--------
					20	2.72	--------	--------
					39	2.48	--------	--------
23	42 49 30 N. 70 40 00 W.	do	10	do	0	3.70	--------	--------
					40	--------	--------	--------
					79	2.89	--------	--------
			11	Apr. 7–8, 1925	0	4.60	--------	--------
					37	2.43	--------	--------
					75	2.48	--------	--------

[1] From hydrometer reading.

[2] These water samples probably were transposed.

TABLE 17.—"*Fish Hawk*" *stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
	° ′ ″							
24	42 50 30 N. 70 43 30 W.	Ipswich Bay	10	Mar. 25, 1925	0	3.60	--------	--------
					16	2.73	--------	--------
					33	2.57	--------	--------
25	42 52 00 N. 70 40 00 W.	do	9	Mar. 12, 1925	0	3.60	[1]31.47	25.04
					25	2.40	[1]32.47	26.16
					49	2.44	[1]33.02	26.39
			10	Mar. 25, 1925	0	3.80	--------	--------
					38	2.63	--------	--------
					75	2.90	--------	--------
			11	Apr. 7-8, 1925	0	4.75	--------	--------
					33	2.87	--------	--------
					65	2.78	--------	--------
26	42 53 30 N. 70 43 00 W.	do	9	Mar. 12, 1925	0	3.70	[1]31.03	24.68
					17	2.36	[1]32.81	26.22
					33	2.40	[1]32.94	26.32
			10	Mar. 25, 1925	0	3.40	--------	--------
					12	3.27	--------	--------
					24	2.64	--------	--------
27	42 54 30 N. 70 40 00 W.	do	10	do	0	3.35	--------	--------
					38	2.63	--------	--------
					76	2.85	--------	--------
28	42 56 00 N. 70 41 45 W.	do	9	Mar. 12, 1925	0	3.10	[1]32.10	25.59
					22	2.60	[1]32.70	26.10
					43	2.60	[1]33.21	26.52
			10	Mar. 25, 1925	0	3.60	--------	--------
					18	2.83	--------	--------
					37	2.59	--------	--------
			11	Apr. 7-8, 1925	0	4.20	[1]29.02	23.04
					26	2.57	--------	--------
					51	2.61	[1]33.15	26.47
29	42 38 00 N. 70 33 30 W.	Off Thatcher's Island	11	Apr. 8, 1925	0	4.55	--------	--------
					20	2.83	--------	--------
					39	2.81	--------	--------
			12	Apr. 22, 1925	0	4.20	[1]31.13	24.72
					22	4.23	--------	--------
					44	3.56	[1]32.00	25.47
			13	May 21, 1925	0	7.10	[1]31.44	--------
					32	3.38	[2]32.61	--------
					64	3.21	[2]32.42	--------
			14	June 17, 1925	0	12.91	32.09	24.19
					10	12.24	32.09	24.30
					20	11.87	32.09	24.37
					48	5.19	32.88	26.00
30	42 38 00 N. 70 25 00 W.	Offing of Cape Ann	11	Apr. 8, 1925	0	4.30	--------	--------
					42	3.13	--------	--------
					84	3.11	--------	--------
			12	Apr. 22, 1925	0	4.00	[1]31.79	25.26
					40	3.42	[1]32.38	25.75
					80	2.92	[1]32.82	26.17
			13	May 22, 1925	0	9.40	[1]31.11	24.05
					25	3.51	[1]32.21	25.65
					50	3.30	[1]32.21	25.66
			14	June 17, 1925	0	13.33	32.38	24.31
					10	12.08	32.66	24.78
					20	6.39	32.95	25.91
					40	4.23	33.24	26.38
					75	4.04	33.24	26.40
31	42 30 00 N. 70 20 00 W.	On line Cape Ann-Cape Cod	11	Apr. 7, 1925	0	4.05	[1]32.02	25.45
					57	2.86	--------	--------
					112	2.90	[1]32.59	26.00
			12	Apr. 22, 1925	0	4.40	[1]31.30	24.83
					42	2.63	[1]32.47	25.92
					84	2.70	[1]32.81	26.24
			13	May 21, 1925	0	9.40	[1]31.27	24.17
					81	3.12	--------	--------
					162	3.10	[1]32.59	25.98
			14	June 17, 1925	0	12.94	32.66	24.61
					10	9.11	32.74	25.35
					20	5.45	33.10	26.14
					40	4.00	33.17	26.35
					94	3.47	33.24	26.49

[1] From hydrometer reading.

[2] Probably transposed.

TABLE 17.—"*Fish Hawk*" *stations in Massachusetts and Ipswich Bays, December, 1924, to June, 1925*—Continued

Station	Position	General locality	Cruise	Date	Depth	Temperature	Salinity	Density
32	° ′ ″ 42 23 00 N. 70 15 00 W.	Midway between Cape Cod and Cape Ann	11	Apr. 7, 1925	0	4.40	--------	--------
					30	3.33	--------	--------
					60	2.72	--------	--------
			12	Apr. 22, 1925	0	4.30	[1]31.47	24.98
					25	4.11	[1]31.66	25.16
					50	3.00	[1]32.41	25.84
			13	May 21, 1925	0	9.20	[1]31.66	24.50
					35	3.40	[1]32.41	25.77
					70	3.09	[1]32.56	25.95
			14	June 17, 1925	0	12.43	32.52	24.61
					10	9.62	32.59	25.16
					20	4.56	33.39	26.47
					50	3.97	33.17	26.53
33	42 15 00 N. 70 10 00 W.	North of Cape Cod	11	Apr. 7, 1925	0	4.60	[1]31.91	25.00
					40	3.69	--------	--------
					80	2.91	[1]33.18	26.46
			12	Apr. 22, 1925	0	4.40	[1]32.00	25.39
					32	4.18	[1]32.57	25.87
					64	3.06	[1]32.65	26.01
			13	May 21, 1925	0	8.30	[1]31.74	24.68
					25	5.04	[1]32.26	25.54
					50	3.28	[1]32.52	25.91
			14	June 17, 1925	0	12.94	32.59	24.56
					10	11.81	32.45	24.65
					20	5.20	33.17	26.22
					50	4.09	33.17	26.34
34	42 08 00 N. 70 06 00 W.	Off Cape Cod	11	Apr. 7, 1925	0	4.40	[1]32.01	25.39
					22	2.94	--------	--------
					44	3.12	[1]32.68	26.05
			12	Apr. 22, 1925	0	4.50	[1]31.86	25.26
					25	4.02	[1]32.01	25.44
					50	3.48	[1]32.91	26.22
			13	May 21, 1925	0	9.00	[1]31.59	24.48
					28	4.30	[1]32.29	25.62
					56	3.31	[1]32.36	25.77
			14	June 17, 1925	0	12.11	32.59	24.72
					10	11.06	32.38	24.75
					20	5.56	33.03	26.06
					56	3.91	33.10	26.29
35	42 34 30 N. 70 38 00 W.	Off Eastern Point, Gloucester	12	Apr. 21, 1925	0	4.40	[1]31.26	24.81
					22	4.23	[1]31.66	25.14
					44	3.66	[1]31 86	25.34
			13	May 22, 1925	0	8.00	[1]31.47	24.54
					22	3.78	[1]32.05	25.48
					44	3.31	[1]32.74	26.06
			14	June 17, 1925	0	13.16	32.09	24.13
					10	12.72	32.16	24.27
					20	12.03	32.30	24.50
					40	6.14	32.66	24.70
36	42 30 15 N. 70 43 15 W.	North side of Massachusetts Bay, off Bakers Island.	12	Apr. 23, 1925	0	5.20	[1]31.50	25.06
					22	4.83	[1]31.70	25.12
					44	3.95	[1]31.70	25.15
			13	May 22, 1925	0	6.95	[1]31.87	24.99
					23	3.99	[1]32.51	25.78
					46	3.72	[1]32.47	25.82
			14	June 17, 1925	0	13.53	32.23	24.16
					10	12.15	32.38	24.54
					20	12.06	32.66	24.81
					44	4.61	32.88	26.06
37	42 28 00 N. 70 48 00 W.	Off Marblehead	12	April 23, 1925	0	4.20	[1]31.59	25.08
					19	4.83	[1]31.75	25.16
					38	4.60	[1]32.00	25.38
			13	May 22, 1925	0	8.72	[1]31.71	24.60
					20	4.39	--------	--------
					39	3.69	--------	--------
			14	June 17, 1925	0	12.16	32.38	24.56
					10	10.24	32.45	24.94
					20	9.08	32.66	25.30
					42	5.30	32.88	25.98
38	42 24 15 N. 70 52 15 W.	Off Nahant	12	April 23, 1925	0	6.00	[1]31.47	24.79
					13	4.57	[1]31.40	24.90
					26	4.75	[1]32.09	25.30
			13	May 22, 1925	0	9.25	[1]31.35	24.24
					15	4.33	[1]32.02	25.41
					30	3.86	--------	--------
			14	June 17, 1925	0	12.76	32.16	24.27
					10	9.75	32.52	25.08
					20	8.93	32.52	25.22
					28	5.92	32.81	25.85

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[1] From hydrometer reading.

TABLE 18.—*Temperatures taken from the "Halcyon" in 1925, stations not numbered*

Date	Latitude			Longitude			General locality	Depth	Temperature
	°	′	″	°	′	″			
Apr. 17	42	41	30	70	28	30	4 miles northeast (mag.) from Cape Ann whistling buoy	0 48	5.50 2.90
18	43	40	00	69	47	00	At Seguin Island whistling buoy	0 29	4.40 2.40
19	44	04	00	68	08	00	7 miles off Great Duck Island, off Mountain Desert Island	0 18 37 55 91	3.10 3.05 2.98 2.80 2.87
June 4	43	08	00	69	40	00	Platts Bank	0 18 36 55 73	10.00 5.80 4.50 4.20 4.10
7	41	42	00	69	48	00	6 miles east of Chatham	0 42	12.70 6.54
7	41	25	45	69	42	00	1 mile south-southeast from Round Shoal whistling buoy	0 29	8.30 8.36
11	41	28	30	69	34	00	7 miles east from Round Shoal whistling buoy	0 37	11.60 6.34
July 9	44	10	15	68	16	30	1 mile west from Little Duck Island, Me	0 29	8.80 7.85
13	44	20	45	67	56	30	3½ miles west from Petit Manan Lighthouse	0 37	10.50 7.76
15	44	13	15	68	14	30	2½ miles north-northeast from Little Duck Island	0 21	11.90 8.70
18							⅓ mile northeast from White Island, Me	0 42	13.30 6.72
20	43	08	30	69	40	30	Platts Bank	0 37 80	18.80 7.90 4.48
22	43	35	00	70	07	00	Cod Ledges (off Portland, Me.)	0 20	14.40 8.52
23	43	07	45	70	25	40	Between Boone Island Lighthouse and whistling buoy	44	5.48
Aug. 7	44	11	15	68	14	25	½ mile northeast from Little Duck Island	0 9 27	11.10 9.10 8.96
20	41	27	00	69	43	00	Round Shoal whistling buoy	0 13 22	11.60 11.36 11.20
21	41	27	00	69	41	15	1 mile east from Round Shoal whistling buoy	0 9 20	11.60 11.58 11.60
21	41	28	20	69	40	20	2 miles east-northeast from Round Shoal whistling buoy	0 15 26	11.60 11.50 11.70
21	41	25	30	69	41	20	1½ miles south-southeast from Round Shoal whistling buoy	0 24	13.30 13.20
23	41	21	00	69	42	50	1 mile northeast from Rose and Crown buoy	0 22	16.40 15.56
21	41	25	30	69	42	20	1 mile south of Round Shoal buoy	0 26	15.00 13.18
23	41	07	15	69	42	45	Great Rip whistling buoy, Mass	0 22	14.10 14.42
24	41	07	15	69	42	45	do	0 13 24	13.80 14.22 14.25
24	41	08	00	69	37	00	4 miles east from Great Rip whistling buoy	0 15	13.80 14.06

TABLE 18.—*Temperatures taken from the "Halcyon" in 1925, stations not numbered*—Continued

Date	Latitude			Longitude			General locality	Depth	Temperature
	°	′	″	°	′	″			
Aug. 24	41	10	00	69	40	00	Off Great Rip	22	14.40
26	42	18	00	70	19	30	Stellwagen Bank	0	16.60
								18	12.06
								35	7.07
Sept. 2	42	47	00	70	19	00	Northwest prong of Jeffreys Ledge	0	16.60
								27	8.68
								51	5.95
3	43	07	00	69	37	30	Platts Bank	0	15.20
								18	9.34
								37	6.14
								70	5.90
3	43	18	30	69	40	00	Between Platts Bank and Portland, Me.	0	14.70
								-----	4.90
								166	5.00
4	-----			-----			1½ miles east-southeast from White Island, Me.	0	13.80
								26	10.20
								31	9.72
5	43	07	45	70	25	45	Between Boone Island Lighthouse and whistling buoy	0	15.50
								51	7.38
9	44	11	15	68	15	00	⅛ mile north of Little Duck Island, Me.	0	11.10
								18	10.23
10	44	13	15	68	13	15	2¾ miles northeast of Little Duck Island, Me.	0	10.80
								18	10.80
								33	10.10
14	44	21	30	67	54	00	1½ miles west of Petit Manan Lighthouse	0	10.50
								18	10.50
								42	10.16
15	43	58	00	68	08	30	Mount Desert Rock	0	9.30
								18	9.26
								37	8.50
								80	7.96
15	44	04	00	68	07	00	Off Mount Desert Rock	0	9.80
								18	9.36
								37	9.08
								55	8.76
								91	8.72
16	44	05	00	68	26	30	Off Swans Island whistling buoy, Me.	0	10.80
								18	9.72
								49	9.42
Oct. 1	41	21	45	69	42	00	2 miles northeast of Rose and Crown buoy	0	12.20
								13	12.70
								26	12.78
1	41	25	00	69	42	00	1½ miles south of Round Shoal buoy	0	11.60
								13	12.00
								24	12.00
1	41	24	00	69	37	00	5 miles southeast of Round Shoal buoy	0	11.60
								13	11.86
								26	13.54
14	44	09	00	68	18	00	¾ mile northeast from Drum Ledge buoy, Mount Desert	0	10.50
								31	8.98
15	44	12	50	68	13	00	2½ miles northeast from Little Duck Island	0	10.80
								9	9.26
								27	9.16
16	44	09	30	68	12	00	2 miles southeast from Little Duck Island	0	10.30
								18	8.74
								37	8.74
22	41	25	30	69	42	30	Round Shoal whistling buoy 1 mile south	0	10.80
								11	9.44
								22	9.38
27	41	17	45	71	00	00	Vineyard Sound whistling buoy	0	13.30
								16	11.90
								33	11.86

TABLE 18.—*Temperatures taken from the "Halcyon" in 1925, stations not numbered*—Continued

Date	Latitude	Longitude	General locality	Depth	Temperature
	° ′ ″	° ′ ″			
27	41 11 00	71 28 00	21 miles east of Block Island	0 11 22	13.00 11.18 11.72
28	41 11 40	70 51 15	½ mile west of No Mans Land gas and whistling buoy	0 18	13.30 12.10

TABLE 19.—*"Albatross II" stations, 1926*

Station	Date	Position	General locality	Depth	Temperature[1]	Salinity	Density
		° ′					
20200	Aug. 11	42 30 N. 70 17 W.	Off Gloucester	0 20 40 100 180	18.00 9.30 5.80 4.75 4.72	31.89 32.60 32.82 32.83 32.86	22.93 25.21 25.88 26.01 26.03
20201	Aug. 12	42 12 N. 69 13 W.	Offing of Cape Cod	0 20 40 100 150 190	19.40 9.65 4.71 3.70 4.57 5.00	--------- 32.85 33.05 33.37 --------- 33.94	--------- 25.36 26.19 26.55 --------- 26.85
20202	...do	41 48 N. 68 10 W.	Northwest edge of Georges Bank	0 15 35 55	15.00 12.25 10.60 7.45	32.59 32.93 32.97 ---------	24.24 24.96 25.28 ---------
20203	Aug. 13	42 06 N. 67 18 W.	North edge of Georges Bank	0 20 40 60	14.70 11.00 10.30 8.30	32.70 to 32.98	--------- --------- --------- ---------
20204	...do	42 07 N. 66 40 W.	Northeast edge of Georges Bank	0 20 40 70	17.77 10.95 7.80 6.30	32.45 32.84 32 91 33.04	23.39 25.12 25.68 25.99
20205	Aug. 14	41 51 N. 66 18 W.	East end of Georges Bank	0 20 40 60	17.20 12.02 8.90 8.80	32.59 32.78 32.93 32.96	23.66 24.88 25.53 25.57
20206	Aug. 15	41 58 N. 66 26 W.	Northeast part of Georges Bank	0 20 40 60	16.94 11.30 7.60 6.10	32.57 32.68 33.04 33.07	23.69 24.94 25.81 26.03
20207	Aug. 17	41 53 N. 66 22 W.	East end of Georges Bank	0 20 40 70	15.50 14.70 10.05 7.95	32.60 32.66 32.95 33.06	24.03 24.25 25.36 25.78
20208	Aug. 18	41 46 N. 66 26 W.	...do	0 20 40 60	15.83 11.80 10.00 9.10	32.60 32.82 32.89 32.94	24.11 24.95 25.32 25.51
20209	Aug. 19	42 28 N. 67 05 W.	Southeast part of basin, north of Georges Bank	0 20 40 100 200 300	16.60 16.70 13.10 5.70 6.60 6.40	32.54 32.54 32.80 33.83 34.79 34.86	23.74 23.72 24.69 26.69 27.33 27.41
20210	Aug. 20	43 11 N. 67 41 W.	Basin, offing of Mount Desert	0 20 40 100 200	16.60 15.90 6.60 4.50 5.80	32.73 32.78 33.08 33.57 34.15	23.88 24.08 24.98 26.62 26.93
20211	...do	43 50 N. 68 33 W.	Near Mount Desert Rock	0 20 40 100 150	14.17 12.15 9.20 5.60 6.05	--------- 32.96 33.06 --------- 34.15	--------- 25.00 25.59 --------- 26.90

[1] Probable error ±0.1°.

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