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 [78]

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

[78] 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

[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).

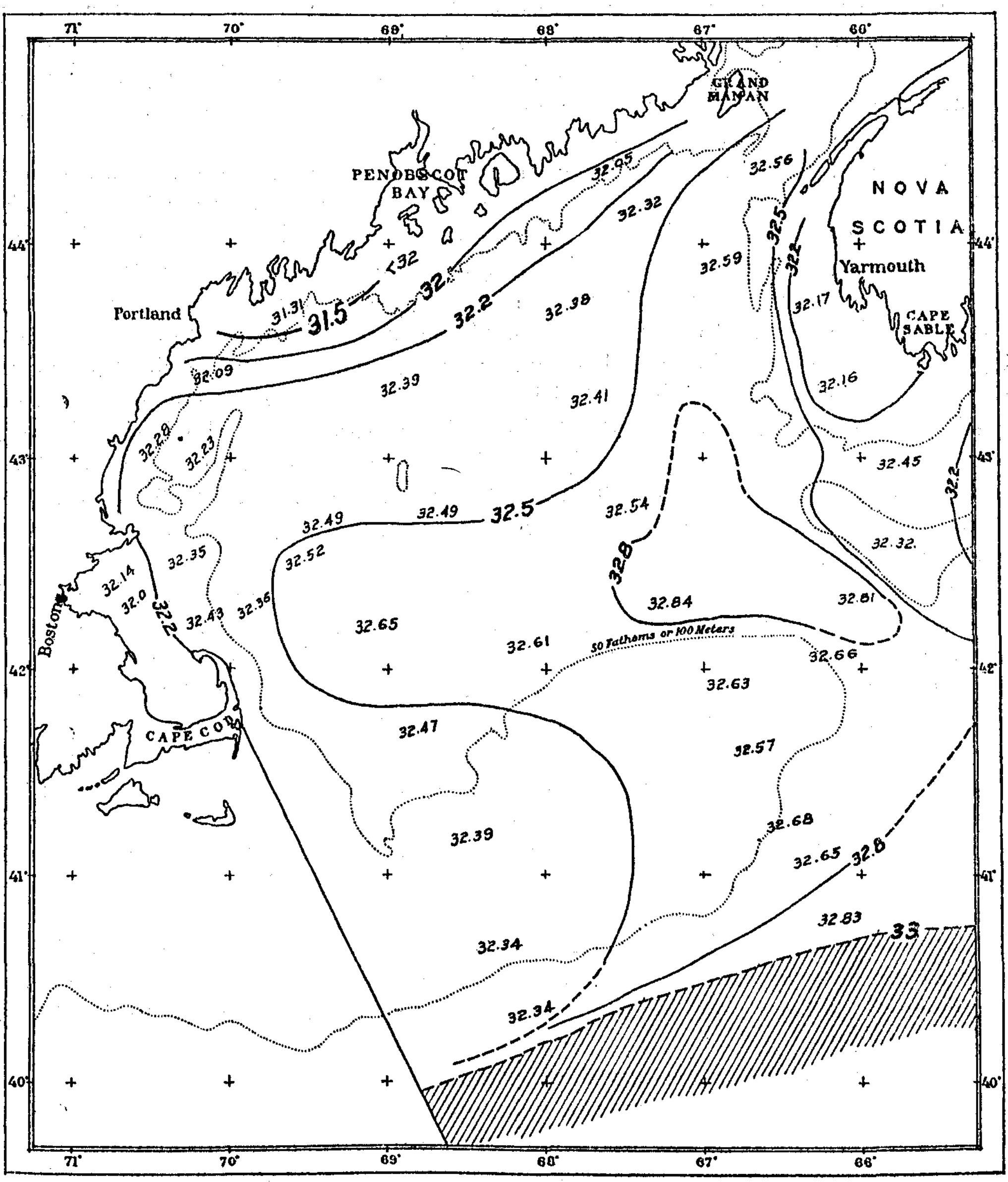

FIG. 91.—Salinity at the surface, February 22 to March 24, 1920. The isohaline for 33 per mille is assumed

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

[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.

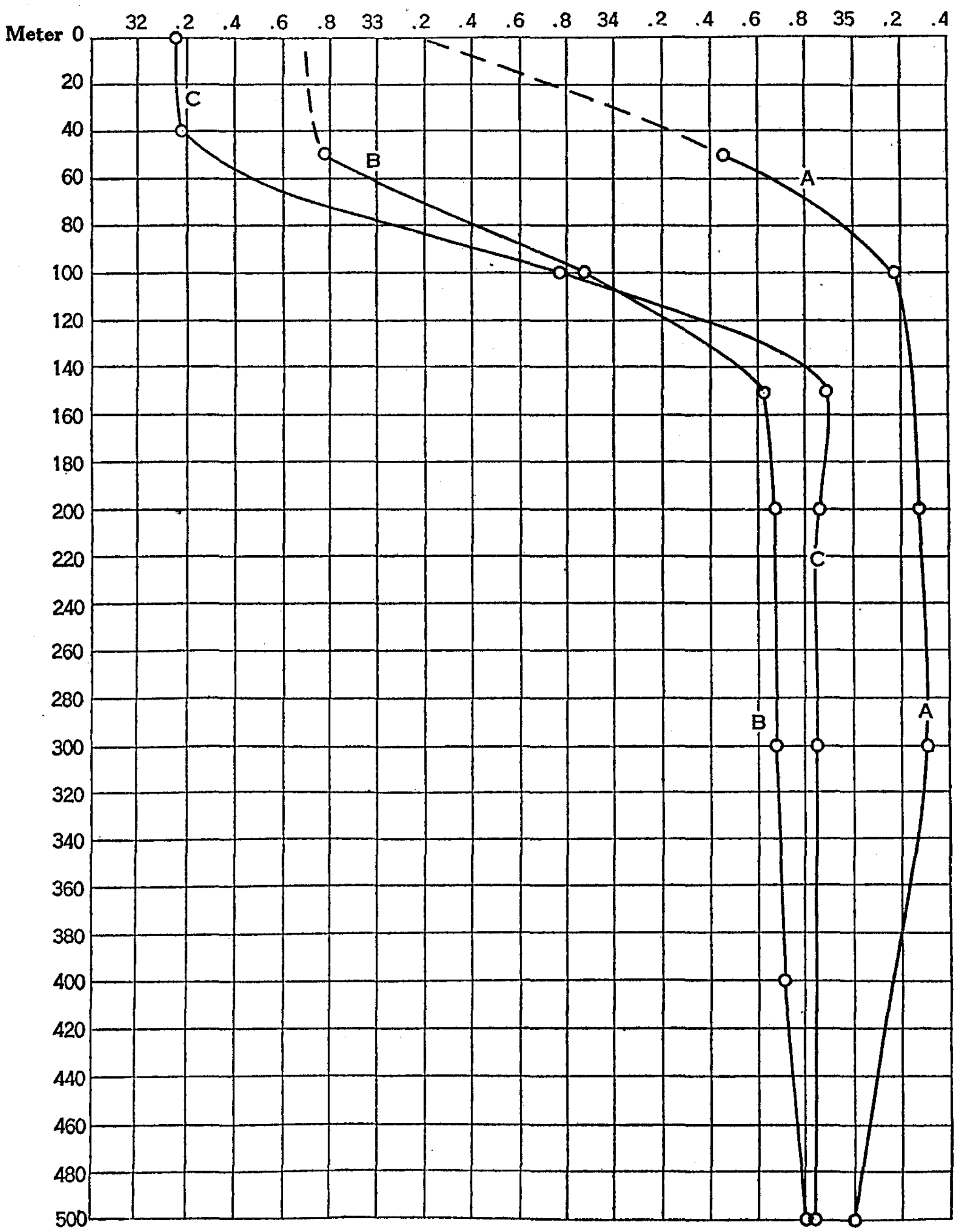

FIG. 92.—Vertical distribution of salinity on the continental slope abreast the gulf and off Shelburne, Nova Scotia, February to March, 1920. A, southwest of Georges Bank, March 22 (station 20044); B, off the southeast slope of Georges Bank, March (station 20069); and C, off Shelburne, Nova Scotia, March (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

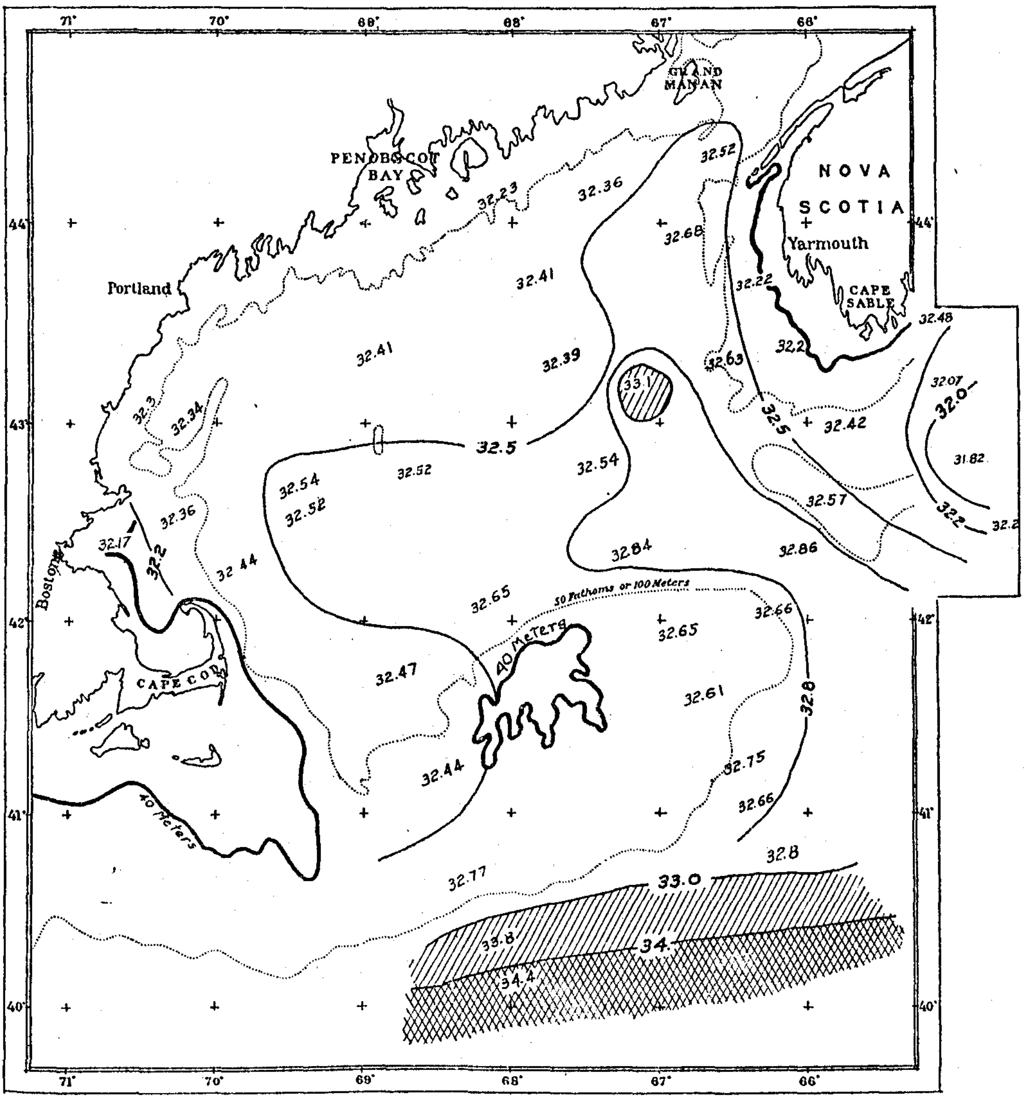

FIG. 93.—Salinity at a depth of 40 meters, February 22 to March 24, 1920

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.

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.

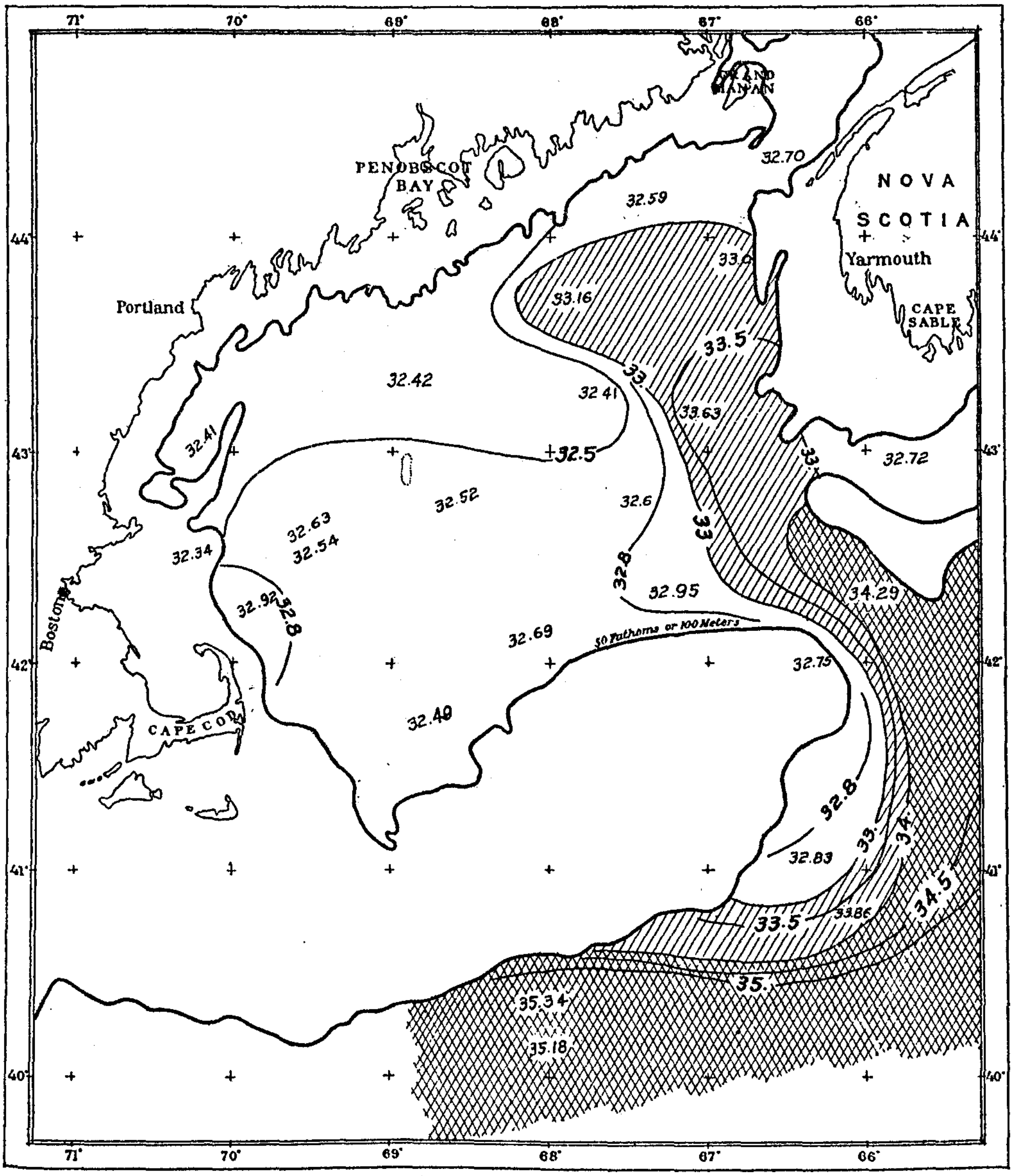

FIG. 94.—Salinity at a depth of 100 meters, February 22 to March 24, 1920

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.

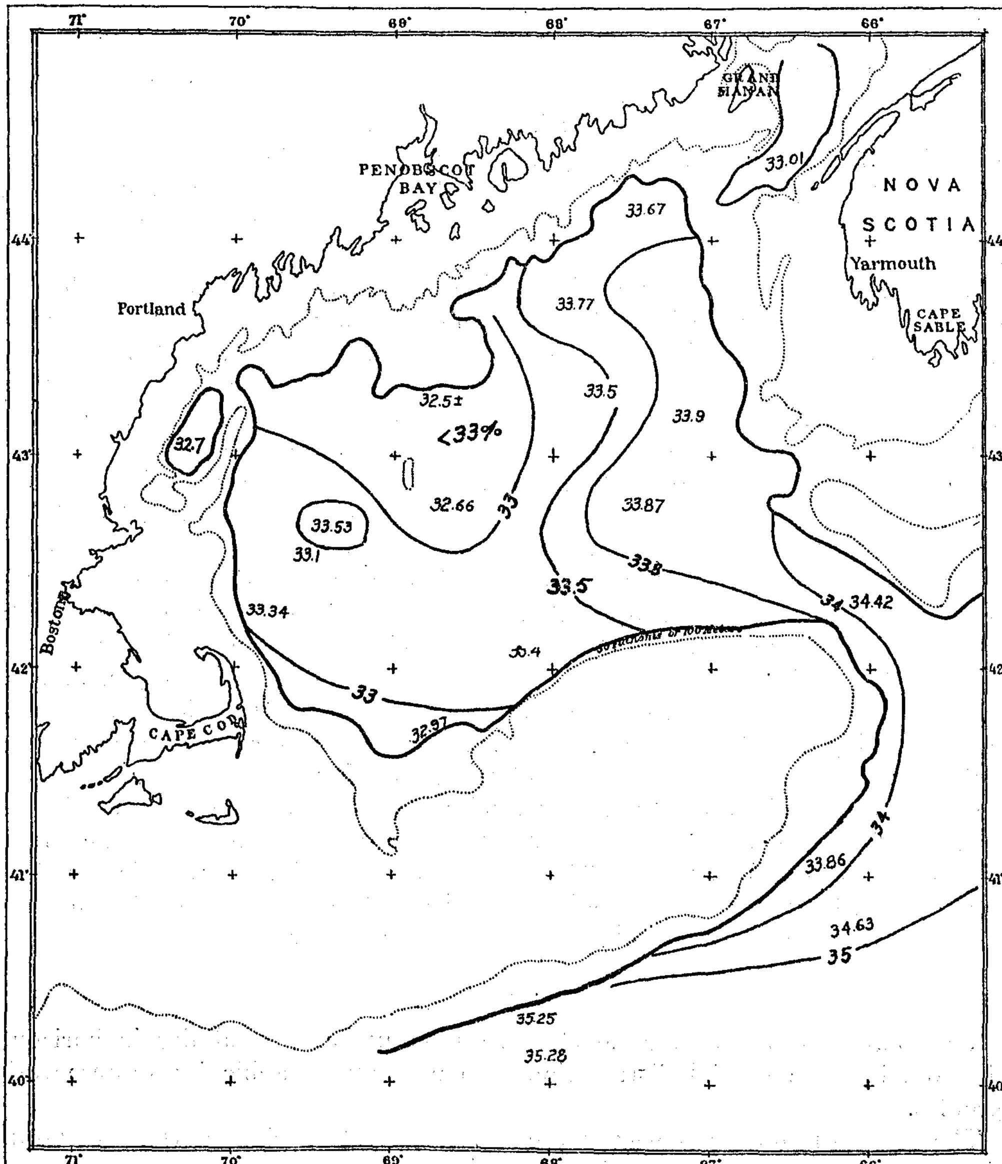

FIG. 95.—Salinity at a depth of 150 meters, February 22 to March 24, 1920

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

[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)

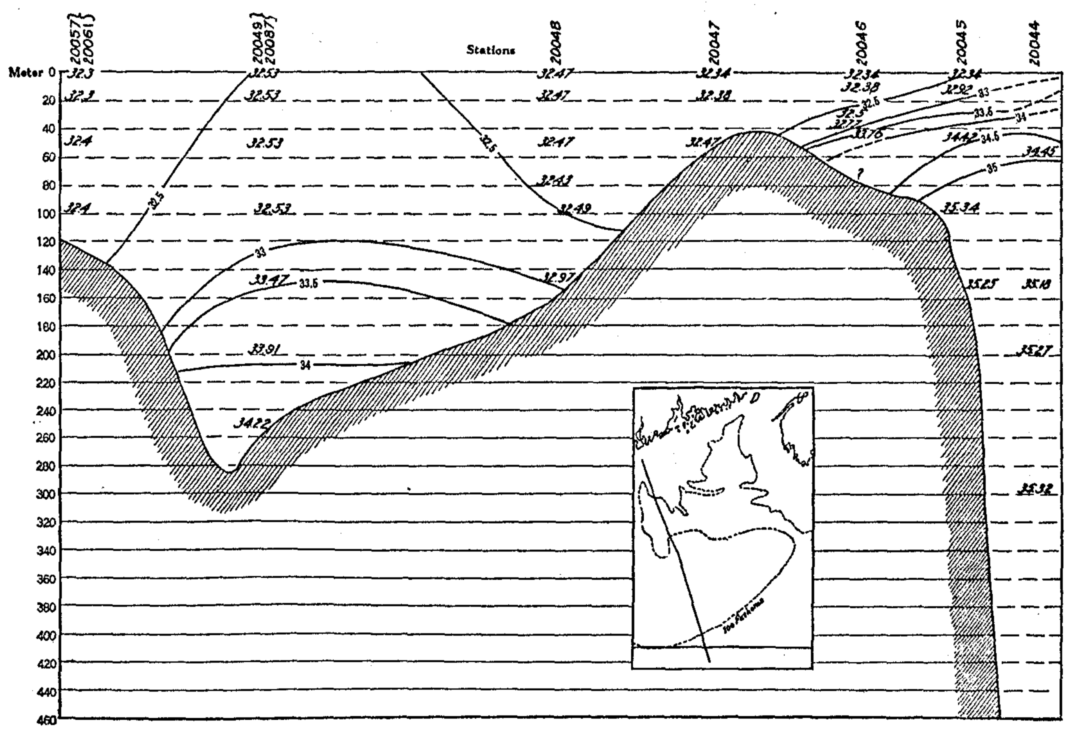

FIG. 96.—Salinity profile running southward from the offing of Casco Bay, across Georges Bank, to the continental slope, February 22 to March 5, 1920

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.

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

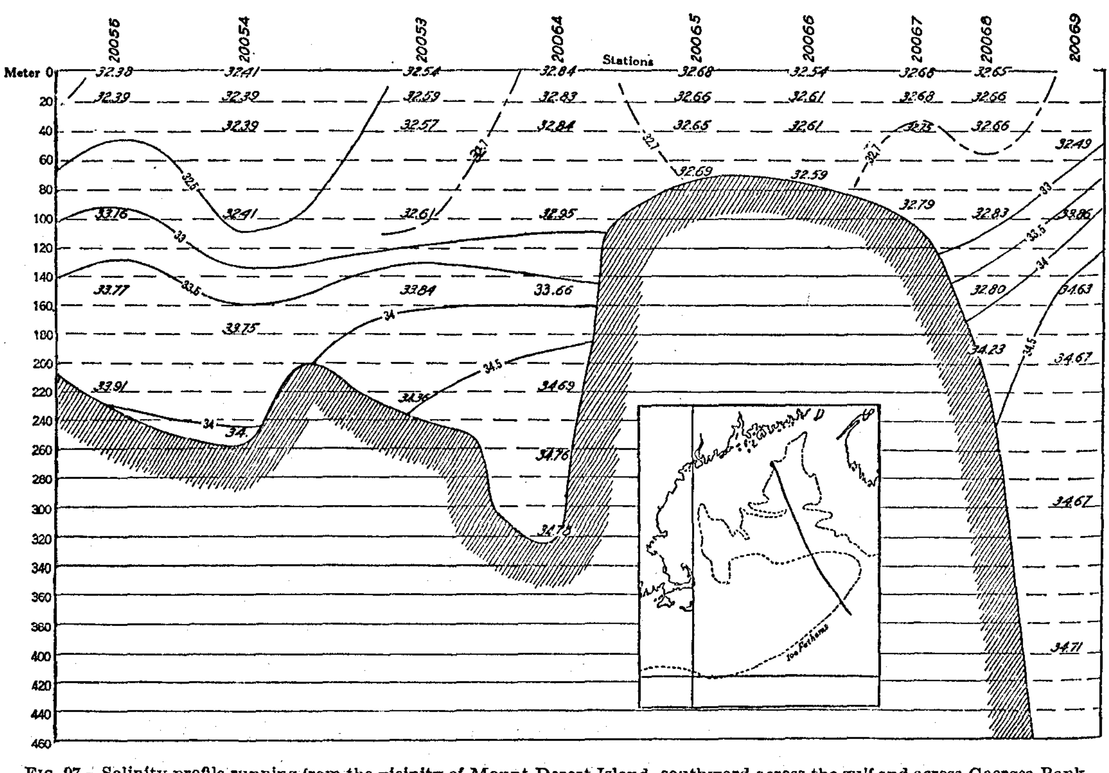

FIG. 97.—Salinity profile running from the vicinity of Mount Desert Island, southward across the gulf and across Georges Bank to the continental slope, March 3 to 12, 1920

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.

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

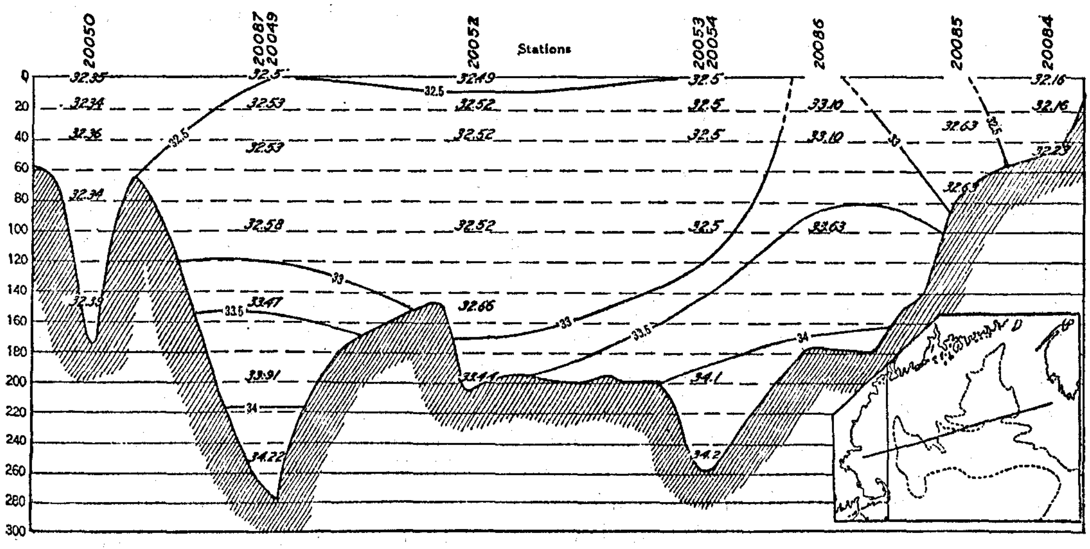

FIG. 98.—Salinity profile running eastward from Massachusetts Bay, across the gulf toward Cape Sable, March 1 to 23, 1920

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.

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

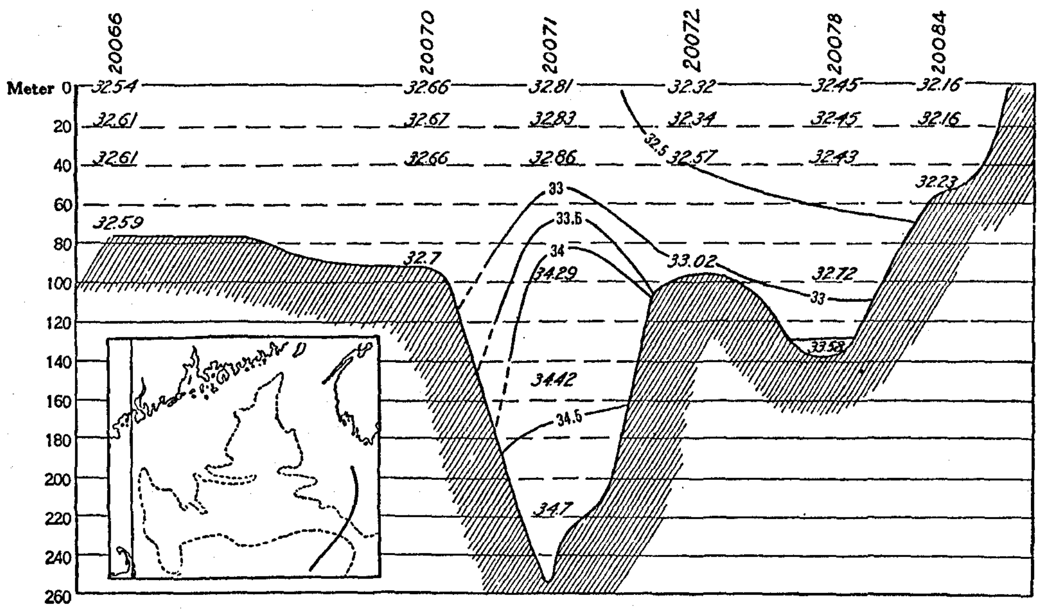

FIG. 99.—Salinity profile running from the eastern part of Georges Bank across the Eastern Channel, Browns Bank, and the Northern Channel, to the offing of Cape Sable, March 11 to 23, 1920

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.

This profile (fig. 99) also corroborates the evidence of the charts (p. 703) that water from the eastward had already 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.

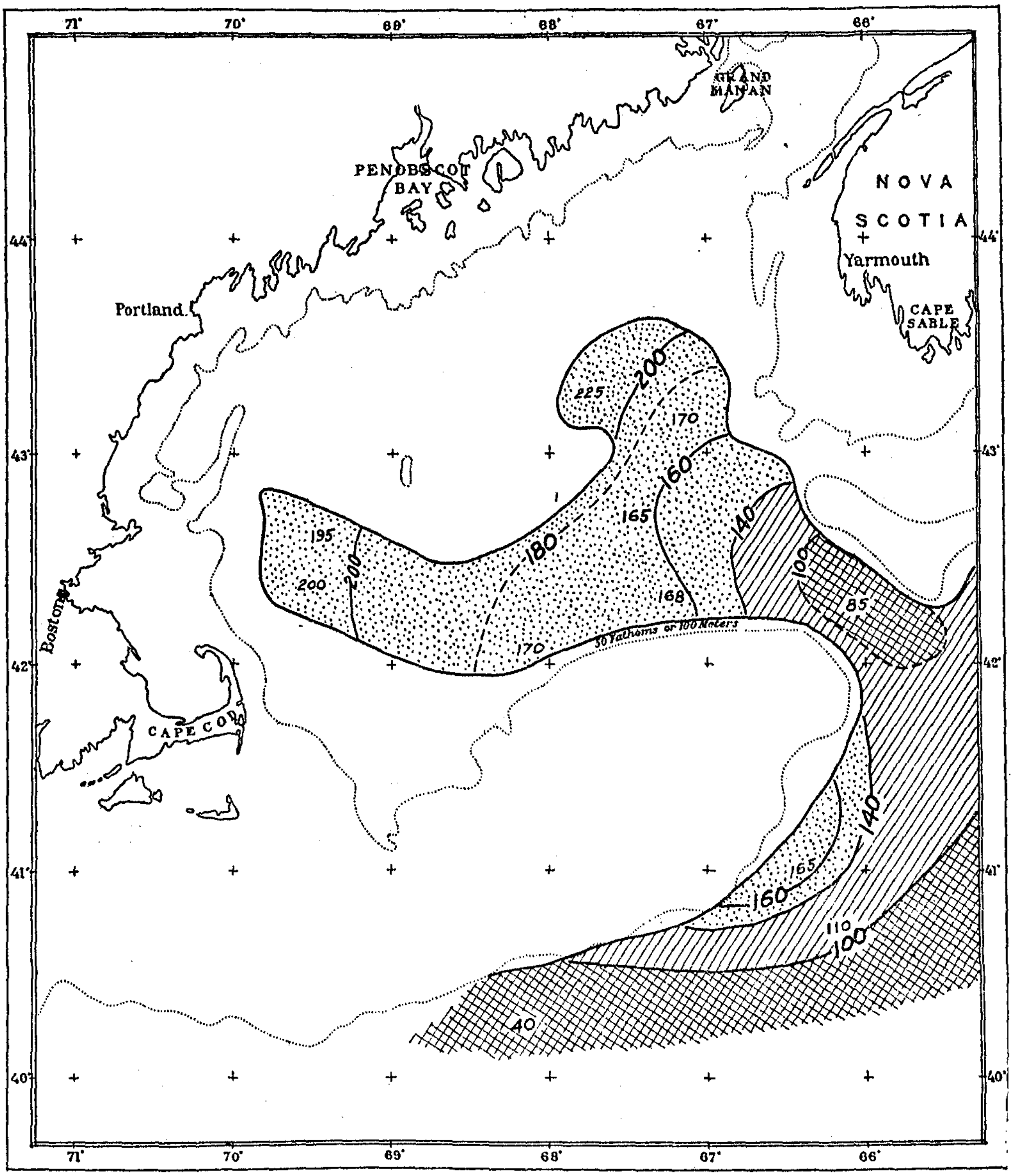

FIG. 100.—Depth below the surface of the isohalobath of 34 per mille, February to March, 1920

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	Mar. 5, 1921	Mar. 5, 1920	Mar. 5, 1921	Mar. 4, 1920	Mar. 4, 1921
	20050	10511	20061	10509	20059	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	32.90		

Depth, meters	Off Seguin Island		Western Basin		
	Mar. 4, 1920	Mar. 4, 1921	Feb. 23, 1920	Mar. 24, 1920	Mar. 5, 1921
	20058	10508	20049	20087	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

[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.

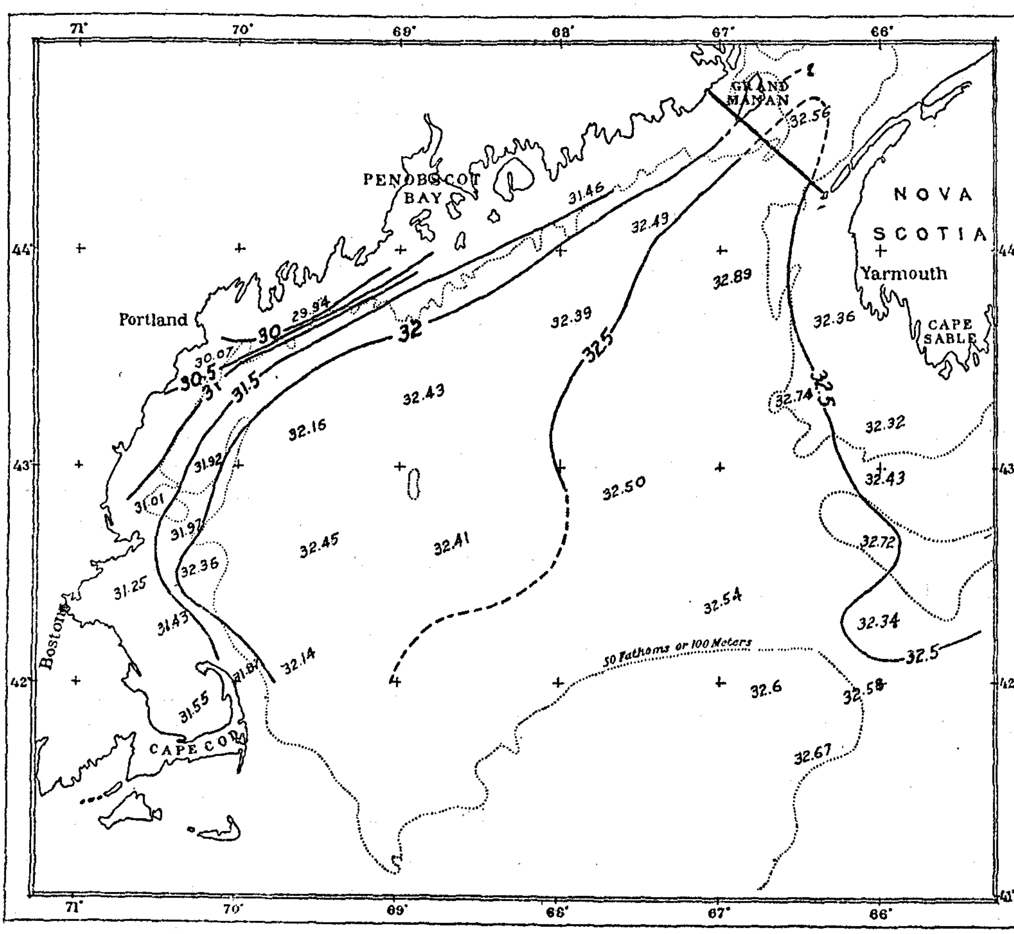

FIG. 101.—Surface salinity, April 6 to 20, 1920 (and for the Bay of Fundy, April 9, 1917; from Mavor, 1923)

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.

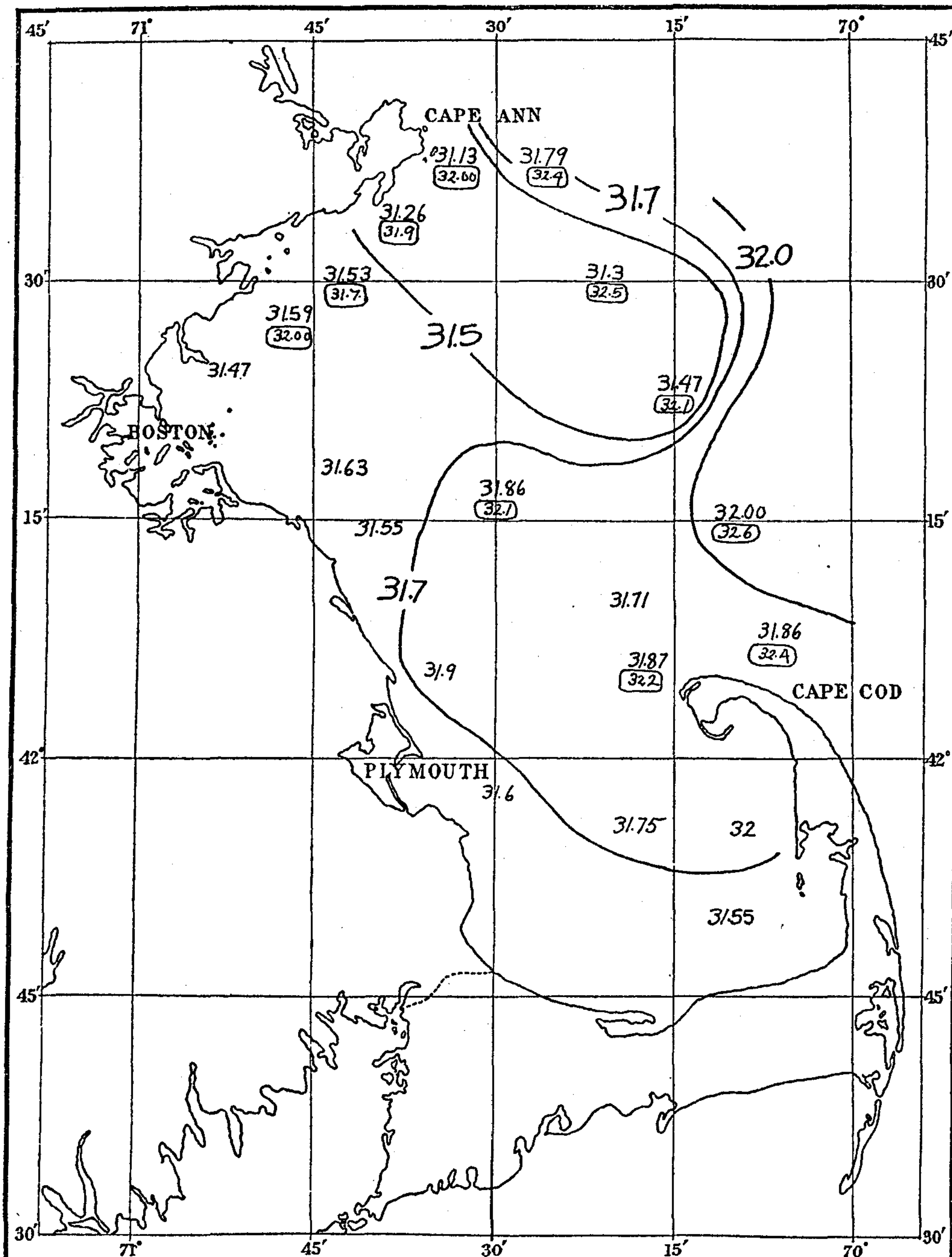

FIG. 102.—Salinity of Massachusetts Bay at the surface (plain figures) and at 40 meters (encircled figures), April 21 to 23, 1925

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]

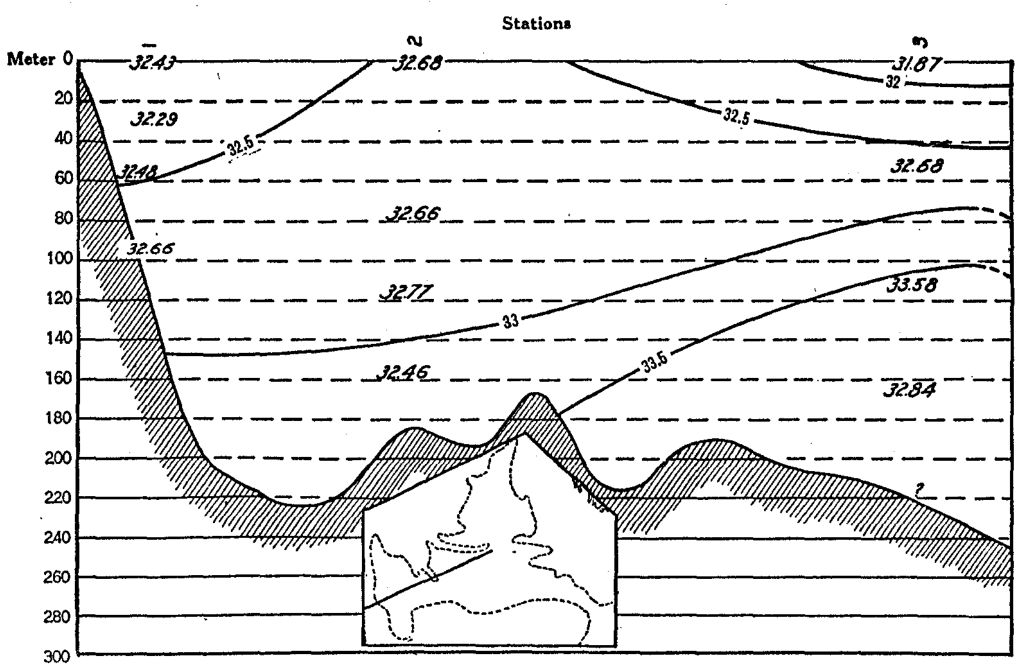

FIG. 103.—Salinity profile running eastward from Cape Cod, March 28 to 29, 1919 (ice patrol stations 1 to 3)

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

[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

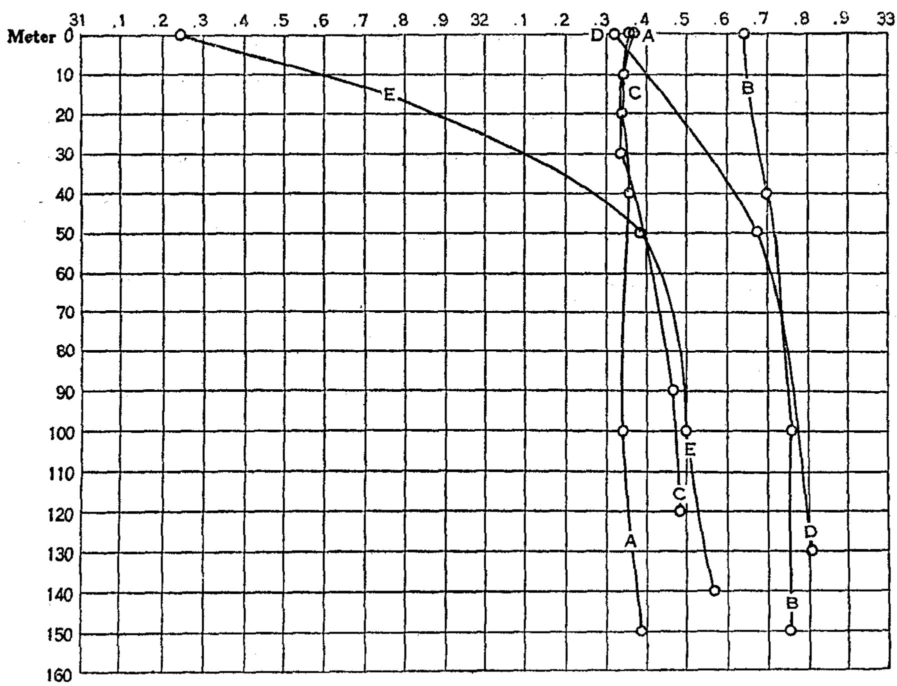

FIG. 104.—Vertical distribution of salinity off Gloucester on March 1, 1920 (A, station 20050), and March 5, 1921 (B, station 10511); for April 9, 1920 (C, station 20090); also for May 4 and August 31, 1915 (D, station 10266, and E, station 10306)

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.

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.

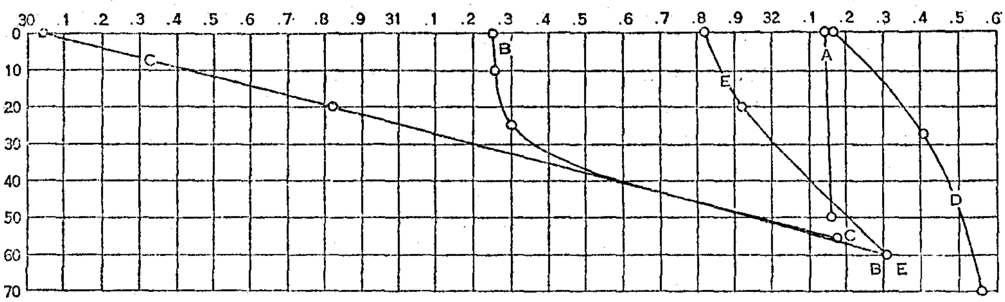

FIG. 105.—Vertical distribution of salinity off Boston Harbor at various seasons. A, March 5, 1920 (station 20062); B, April 6, 1920 (station 20089); C, May 16, 1920 (station 20123); D, August 20, 1913 (station 10106); E, December 29, 1920 (station 10488)

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.

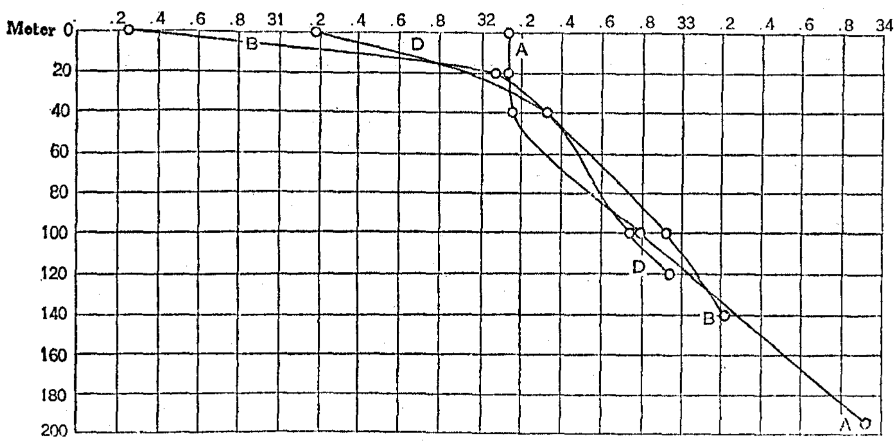

FIG. 106.—Vertical distribution of salinity off northern Cape Cod in various months. A, April 18, 1920 (station 20116); B, May 16, 1920 (station 20125); D, July 14 1913 (station 10213)

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

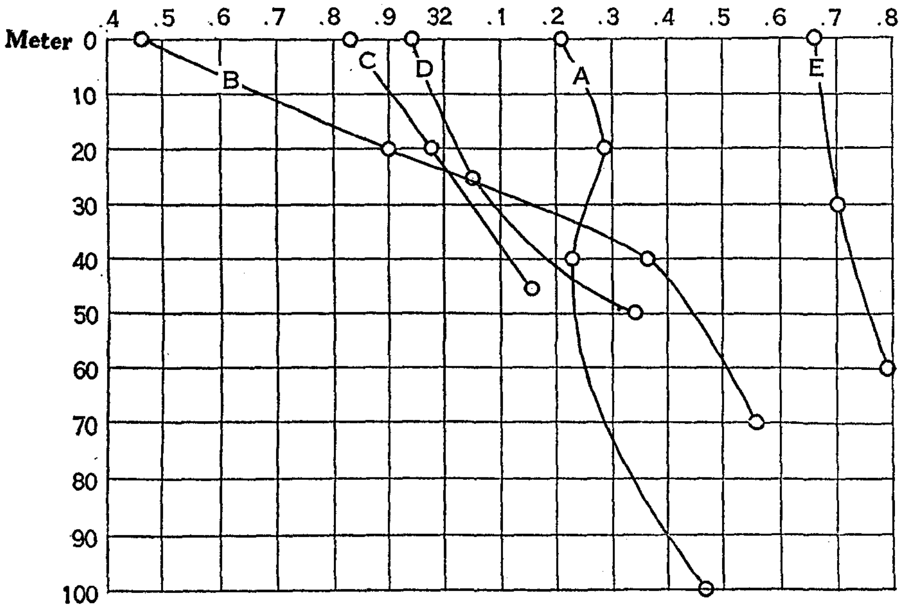

FIG. 107.—Vertical distribution of salinity a few miles off Mount Desert Island in various months. A, March 3, 1920 (station 20056); B, April 12, 1920 (station 20099); C, July 19, 1915 (station 10302); D, August 18, 1915 (station 10305); E, October 9, 1915 (station 10328)

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.

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,

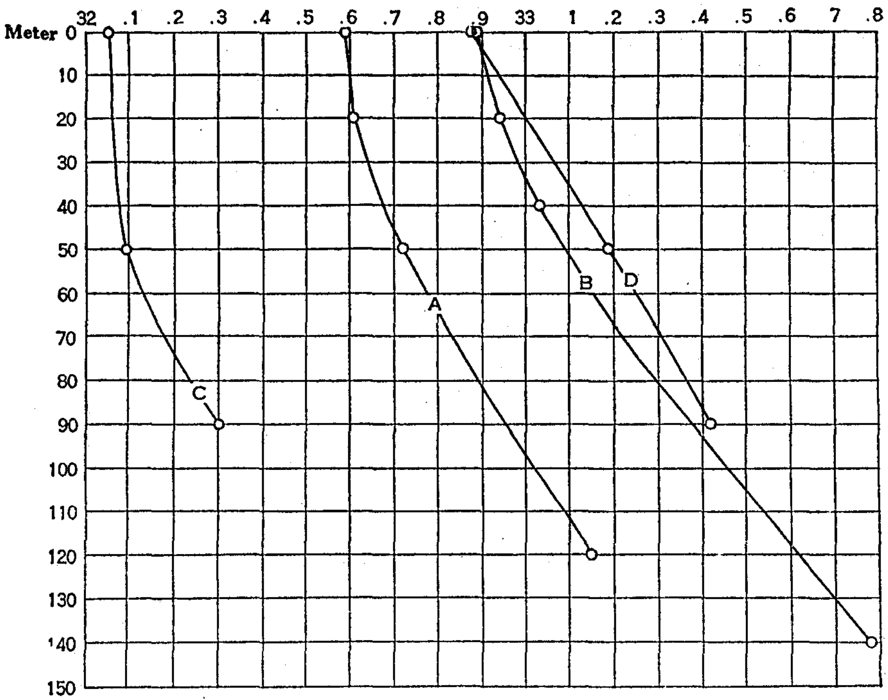

FIG. 108.—Vertical distribution of salinity near Lurcher Shoal. A, March 23, 1920 (station 20082); B, April 12, 1920 (station 20101); C, May 10, 1915 (station 10272); D, September 7, 1915 (station 10315)

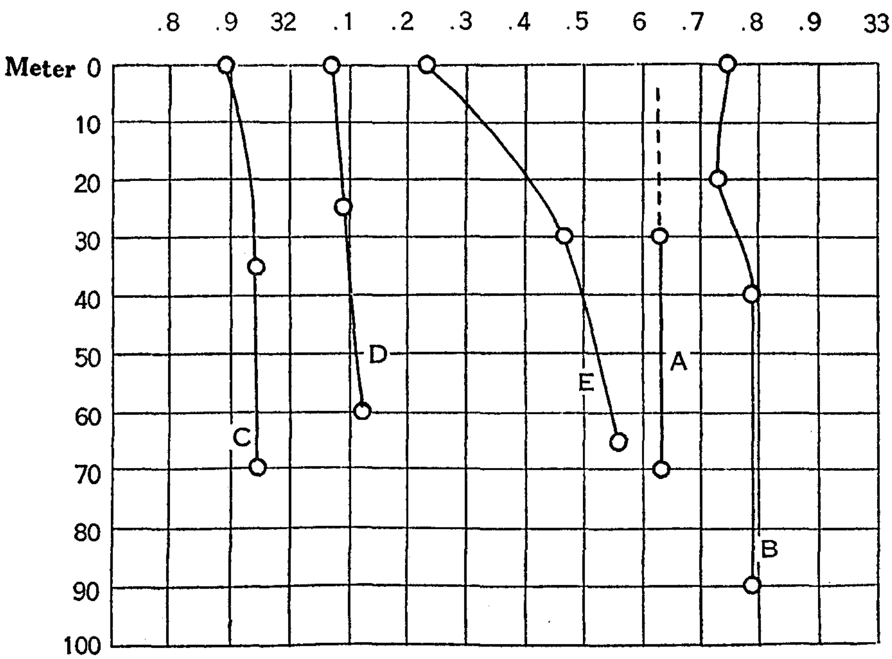

FIG. 109.—Vertical distribution of salinity on German Bank. A, March 23, 1920 (station 20085); B, April 15, 1920 (station 20103); C, May 7, 1915 (station 10271); D, June 19, 1915 (station 10290); E, September 1, 1915 (10311)

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

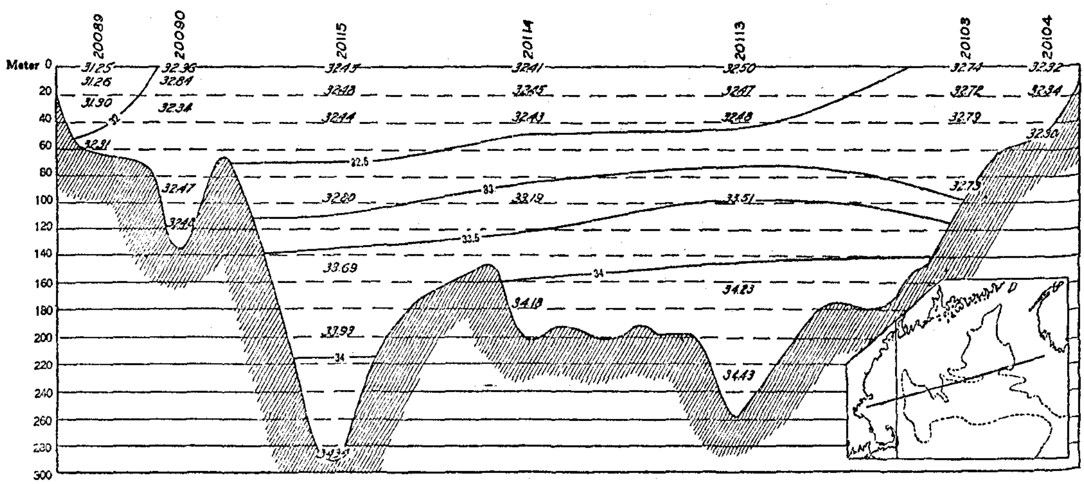

FIG. 110.—Salinity profile running eastward from Massachusetts Bay to the offing of Cape Sable, April 6 to 18, 1920

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.

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).

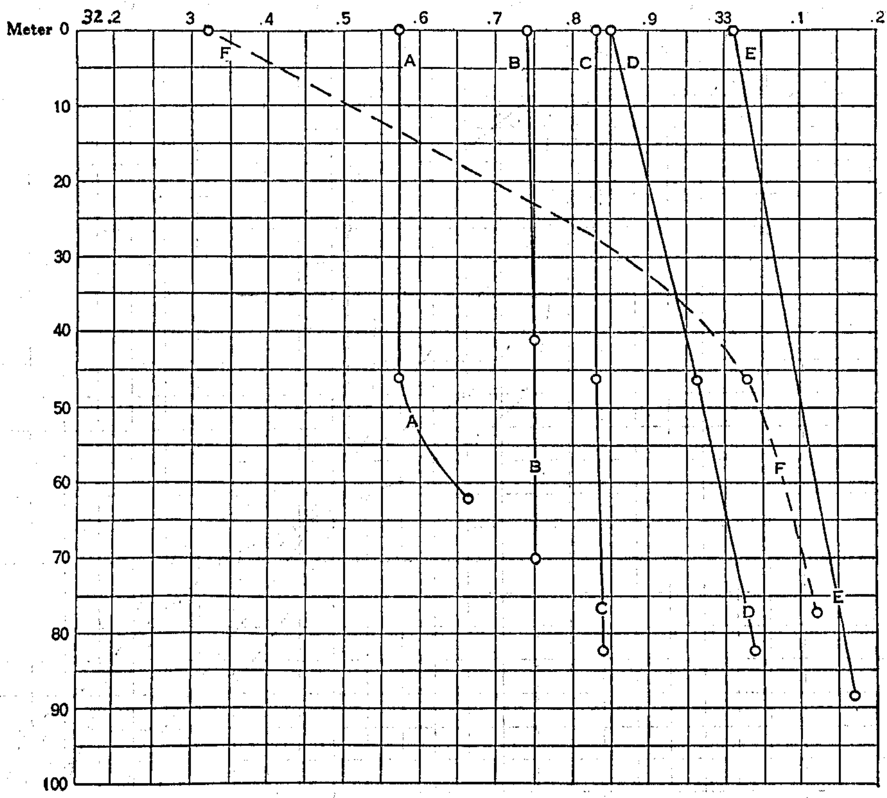

FIG. 111.—Vertical distribution of salinity at the mouth of Massachusetts Bay, off Gloucester, during the winter and spring of 1912-1913. A, November 20 (station 10047); B, December 23 (station 10049); C, February 13 (station 10053); D, March 4 (station 10054); E, March 19 (W. W. Welsh station 1); F, 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).

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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

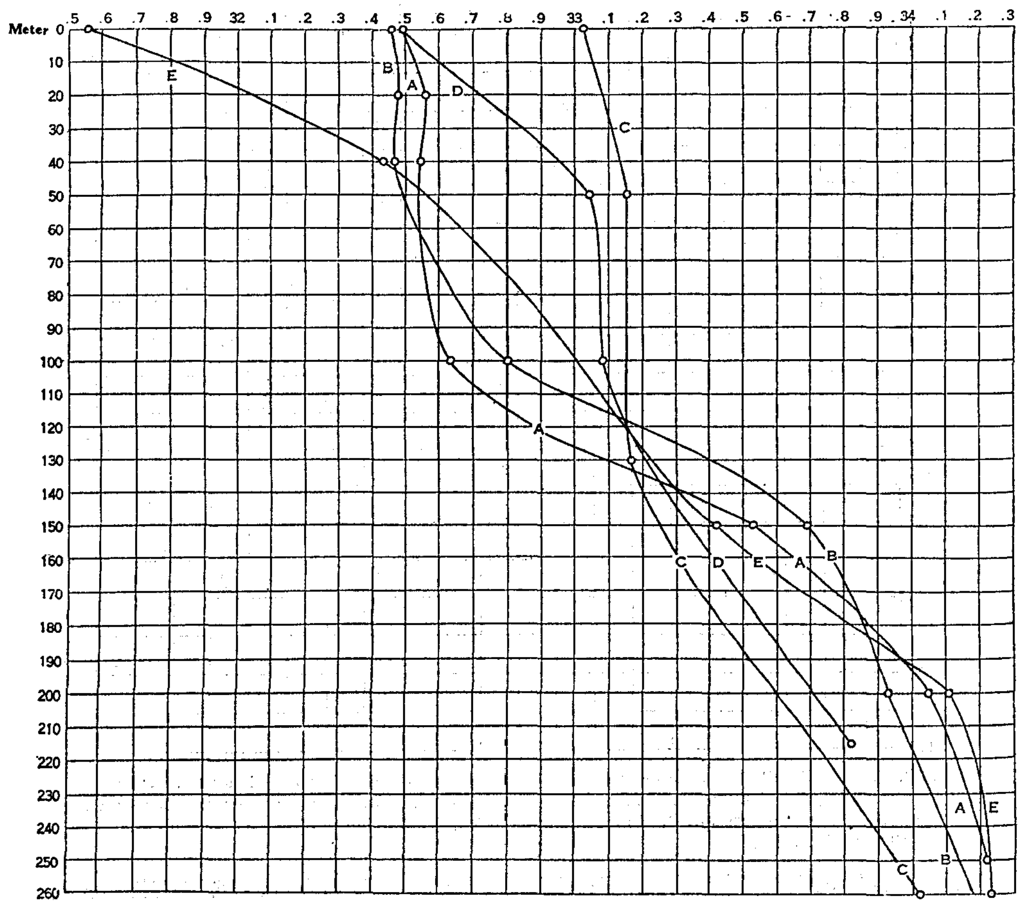

FIG. 112.—Vertical distribution of salinity in the western arm of the basin of the gulf off Cape Ann. A, March 24, 1920 (station 20087); B, April 18, 1920 (station 20115); C, May 5, 1915 (station 10237); D, June 23, 1915 (station 10299); E, August 22, 1914 (station 10254)

cold Nova Scotian water in this direction because accompanied by an increase in temperature.

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

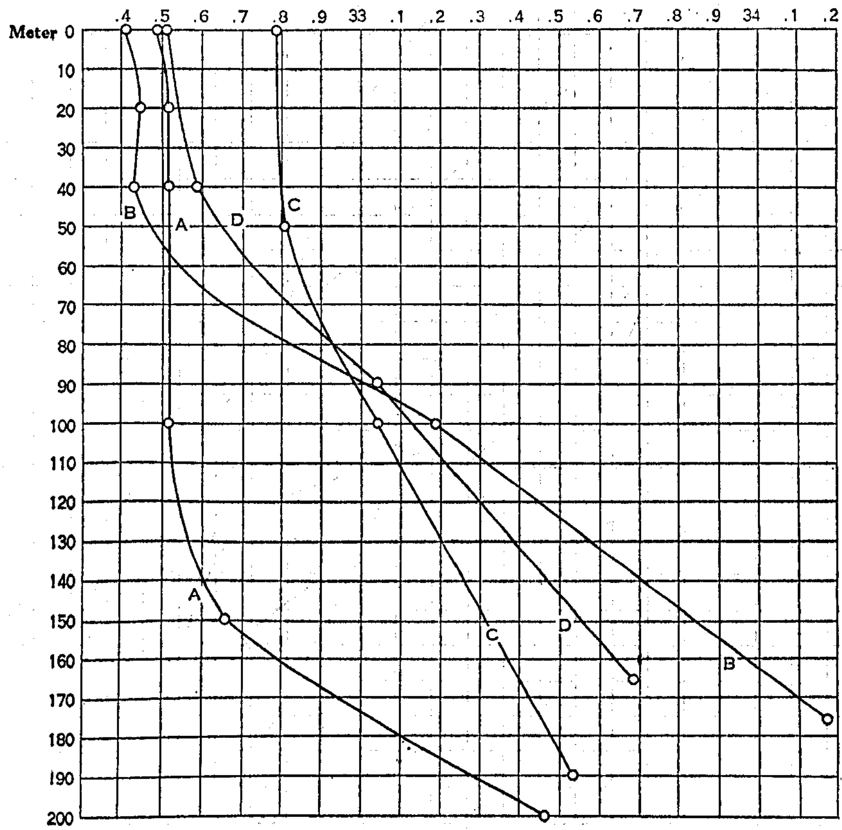

FIG. 113.—Vertical distribution of salinity in the center of the gulf near Cashes Ledge. A, March 2, 1920 (station 20052); B, April 16, 1920 (station 20114); C, May 5, 1915 (station 10268); D, September 1, 1915 (station 10308)

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.

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

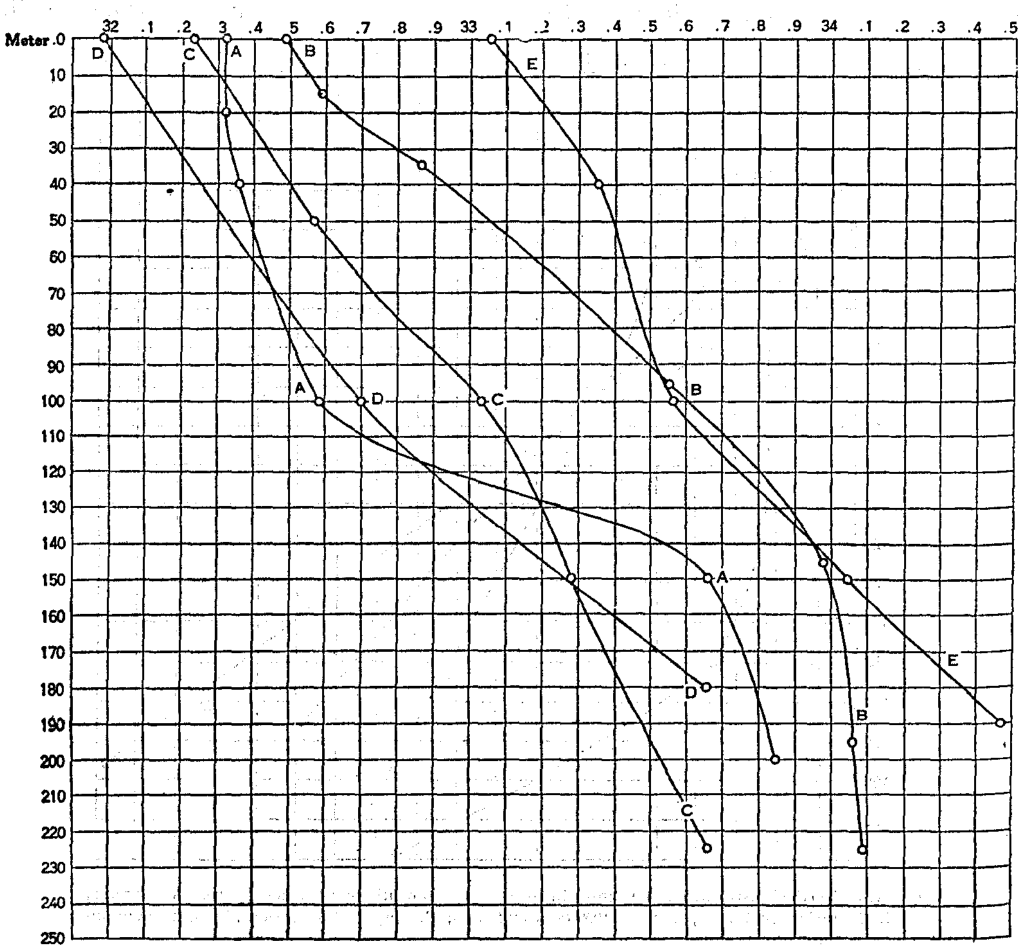

FIG. 114.—Vertical distribution of salinity in the northeastern corner of the gulf. A, March 22, 1920 (station 20081); B, April 12, 1920 (station 20100); C, May 10, 1915 (station 10273); D, June 10, 1915 (station 10283); E, August 12, 1914 (station 10246)

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 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

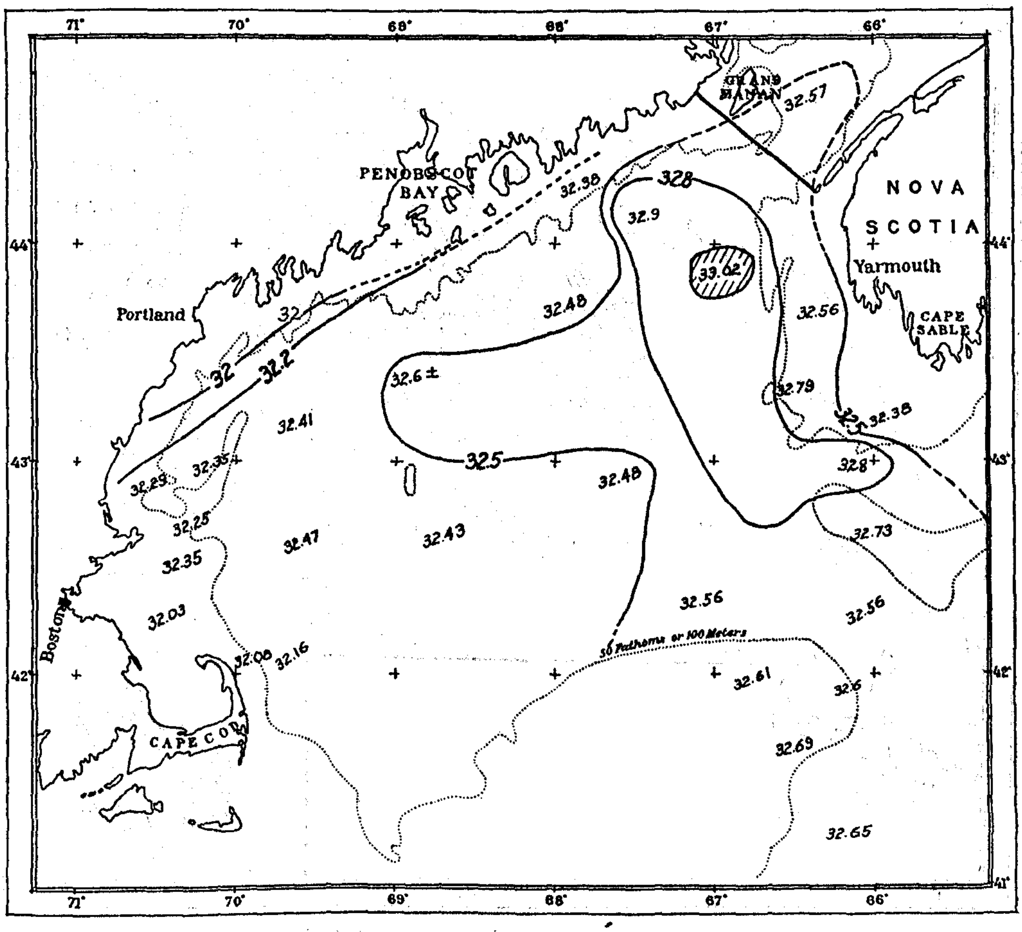

FIG. 115.—Salinity at a depth of 40 meters, April, 1920

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.

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,

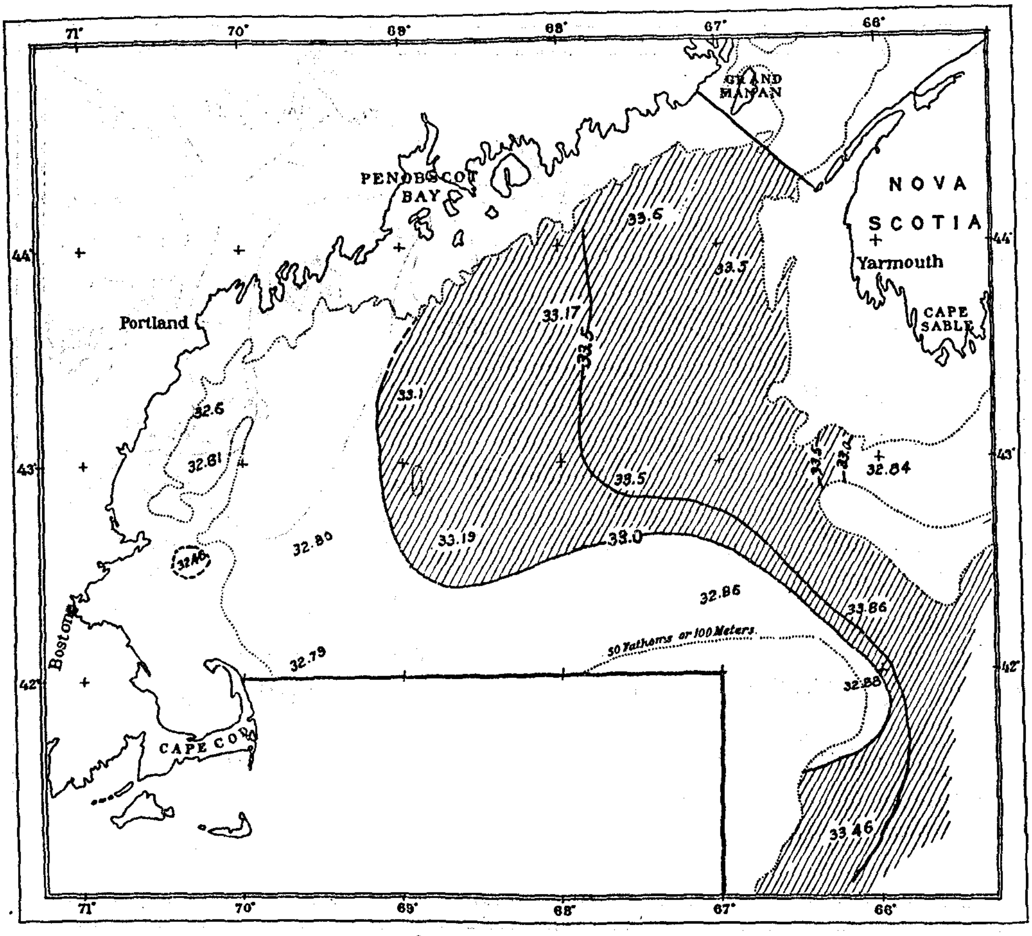

FIG. 116.—Salinity at a depth of 100 meters, April 6 to 20, 1920

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.

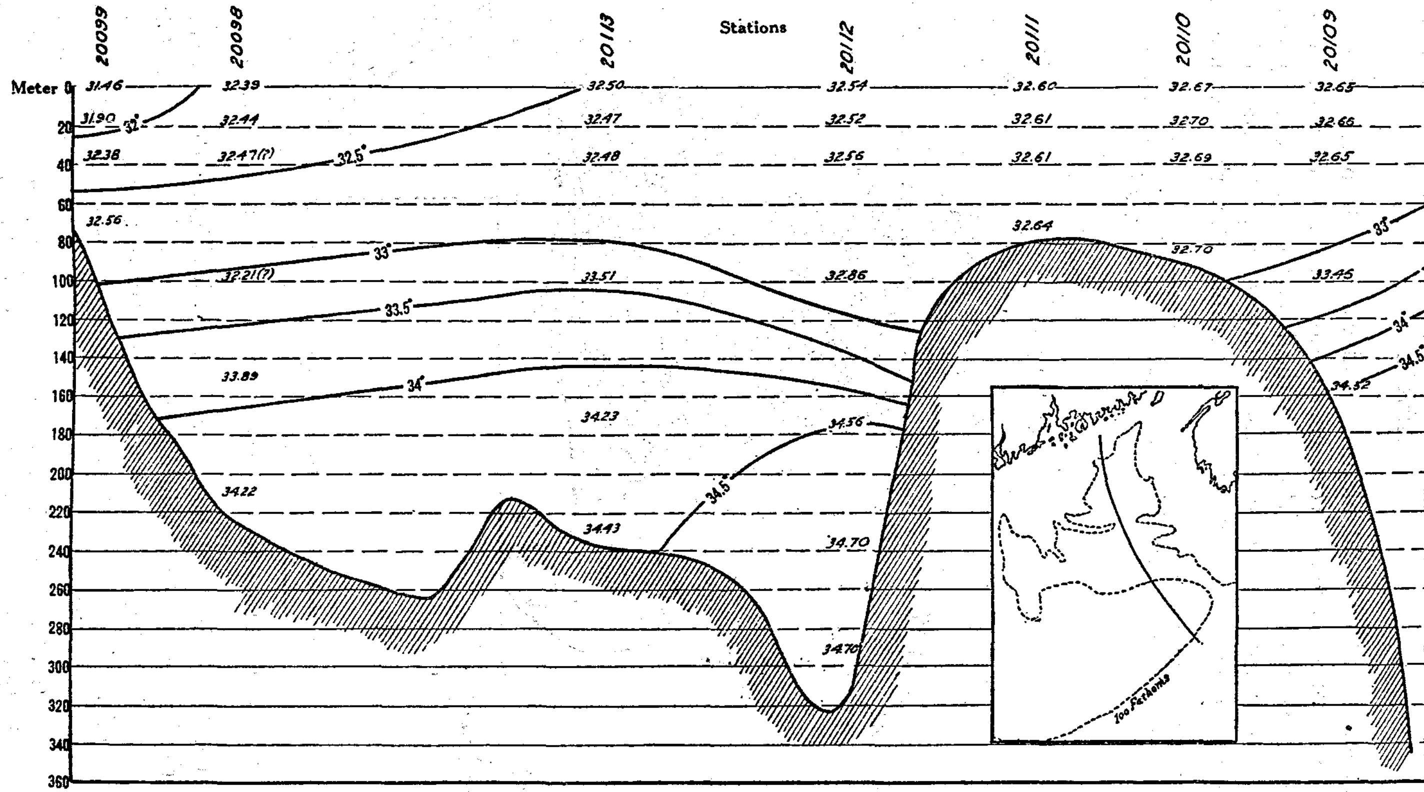

FIG. 117.—Salinity profile, running southward from the offing of Mount Desert Island, across the eastern end of Georges Bank to the continental slope, April 12 to 16, 1920

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

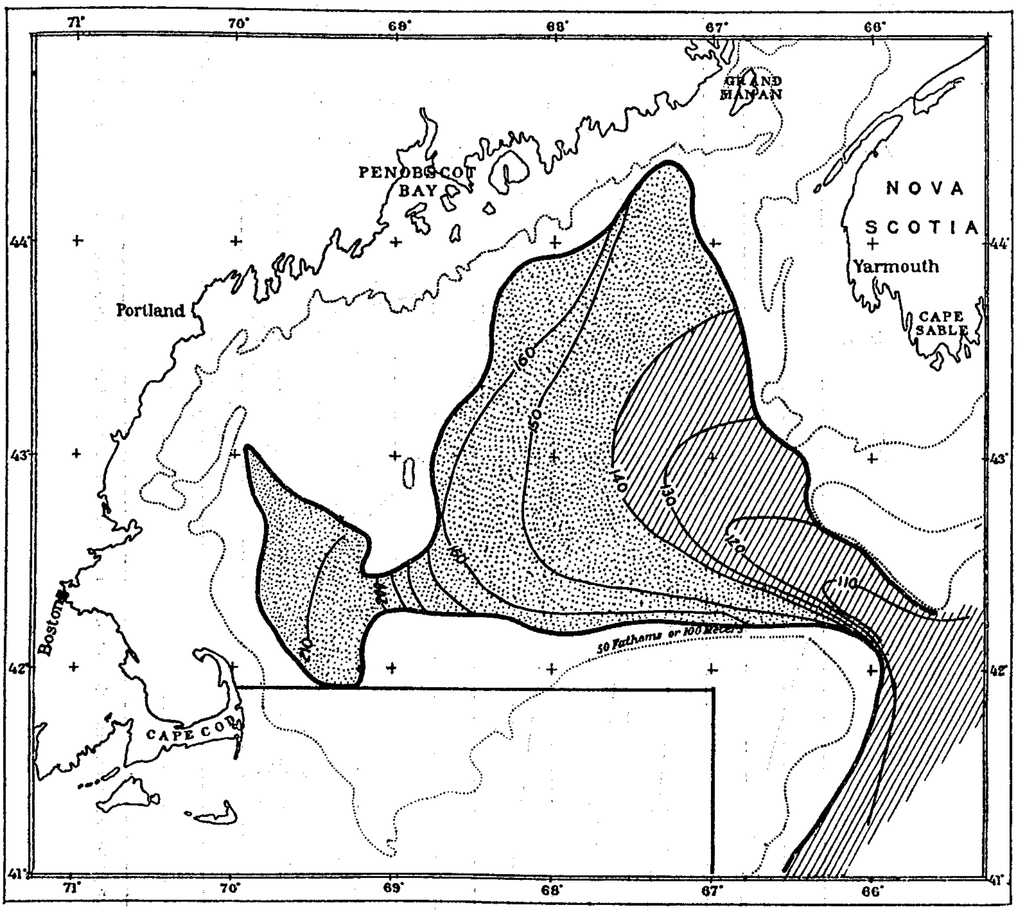

FIG. 118.—Depth below the surface of the isohalobath of 34 per mille, April 6 to 18, 1920

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 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

[87] 31.1 to 31.9 per mille at the surface, averaging 31.6 per mille (*Fish Hawk* cruise 13).

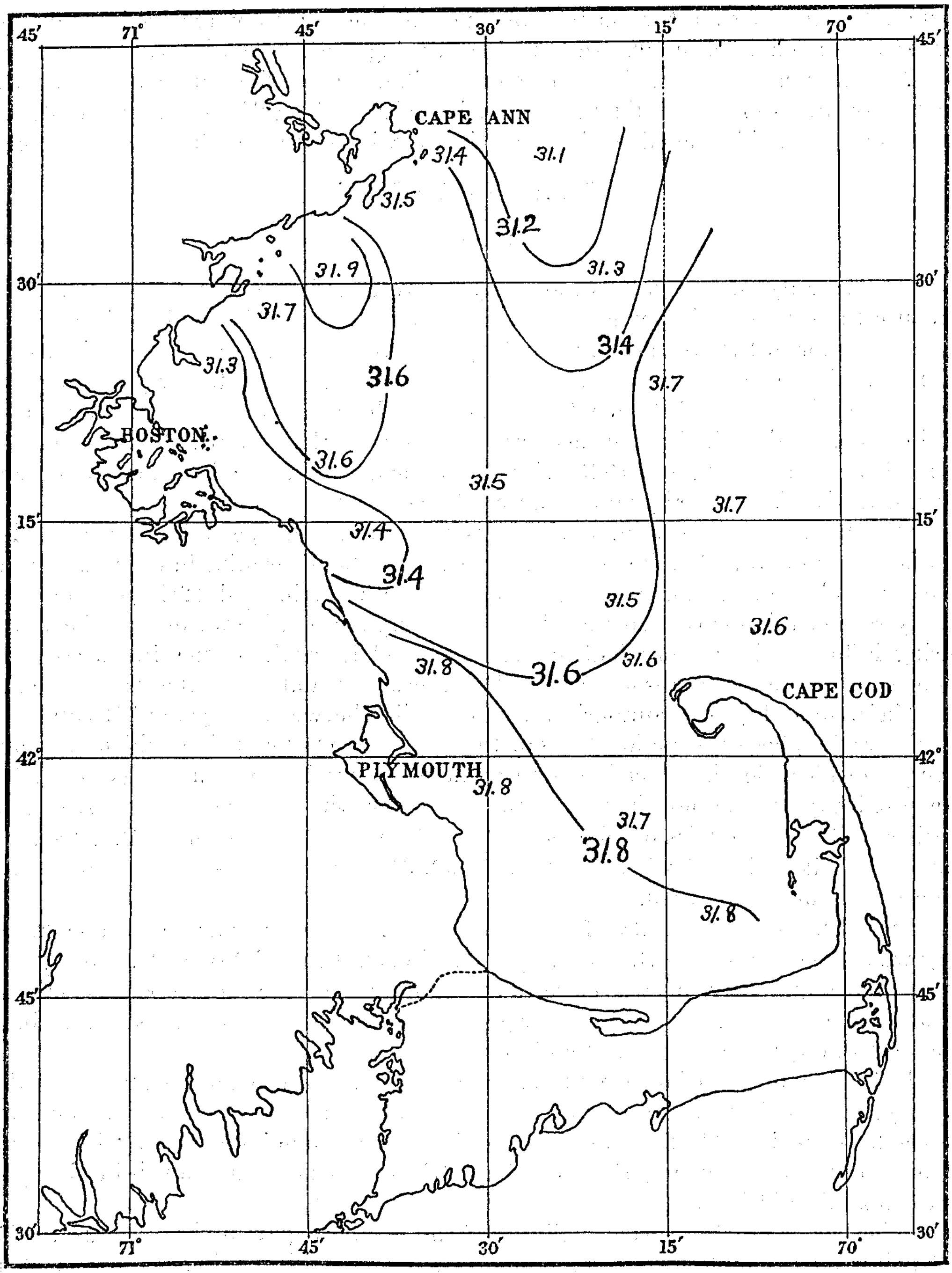

FIG. 119.—Salinity at the surface of Massachusetts Bay, May 20 to 22, 1925, from hydrometer readings

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

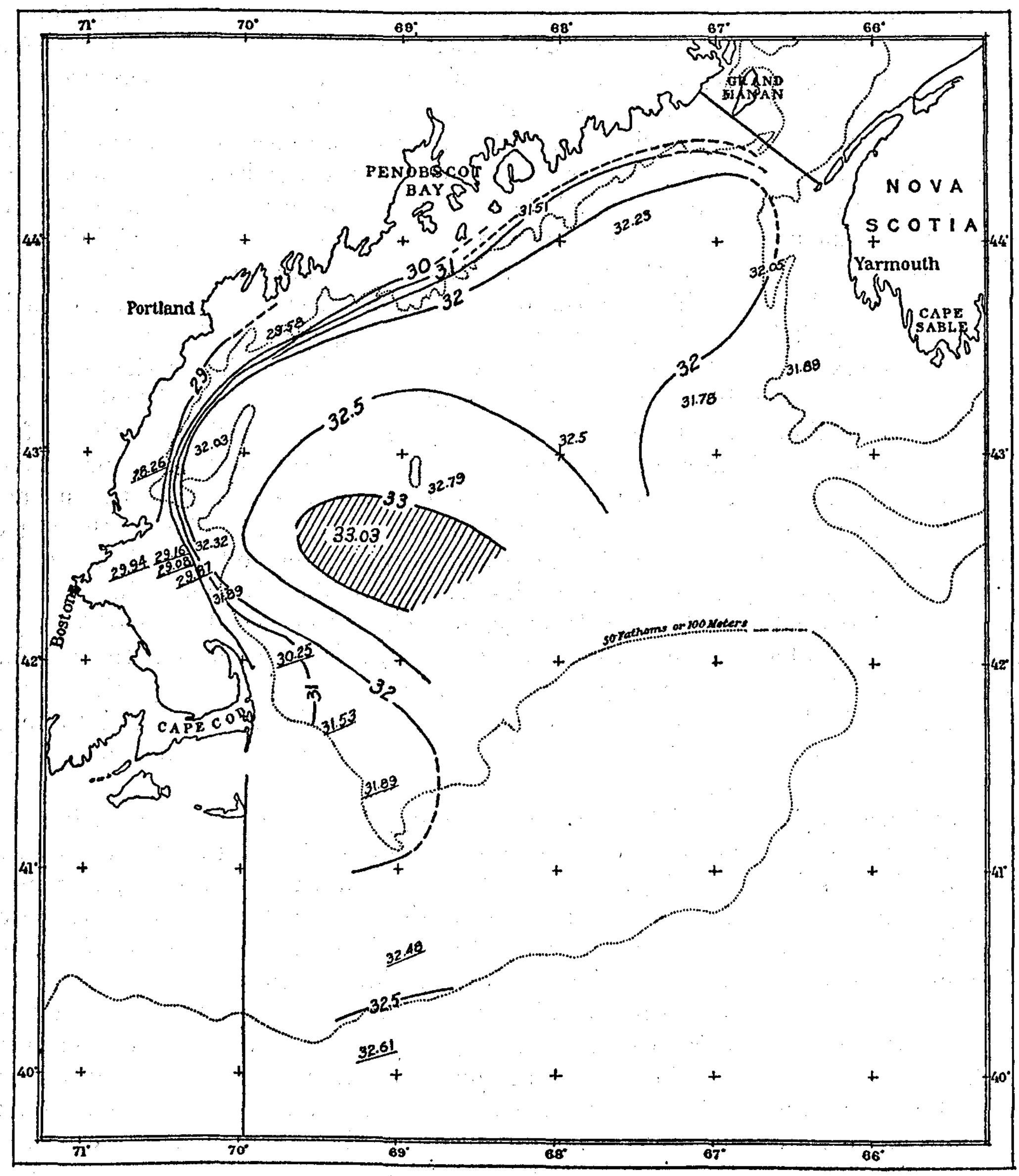

FIG. 120.—Salinity at the surface, May 4 to 14, 1915, combined with May 4 to 17, 1920

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).

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

[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

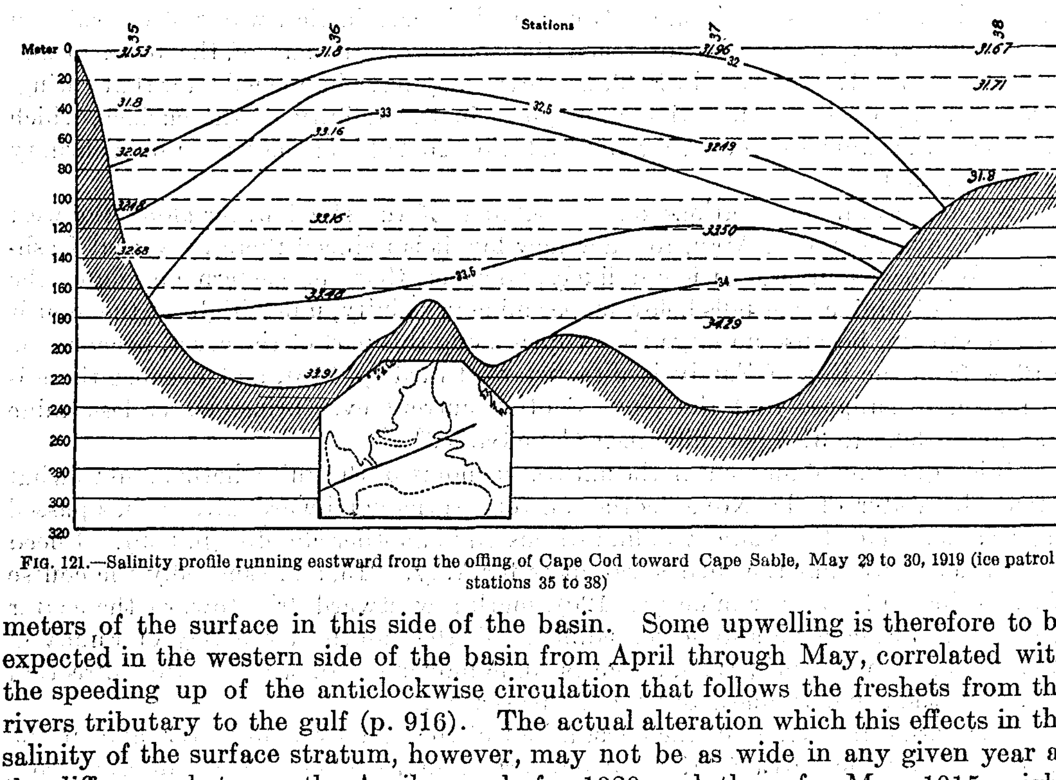

FIG. 121.—Salinity profile running eastward from the offing of Cape Cod toward Cape Sable, May 29 to 30, 1919 (ice patrol stations 35 to 38)

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.

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

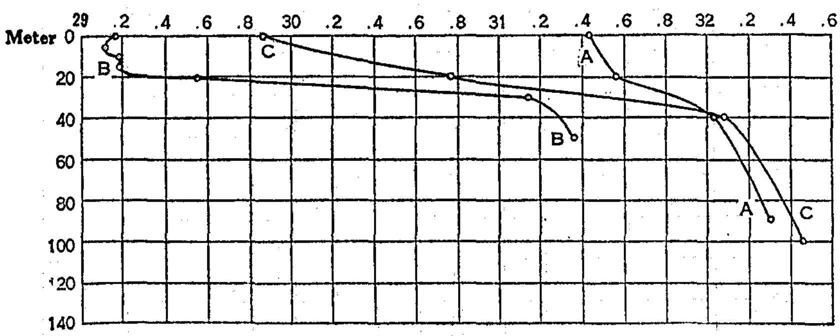

FIG. 122.—Vertical distribution of salinity at the mouth of Massachusetts Bay. A, April 20, 1920 (station 20119); B, May 4, 1920 (station 20120); C, May 16, 1920 (station 20124)

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.

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

[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

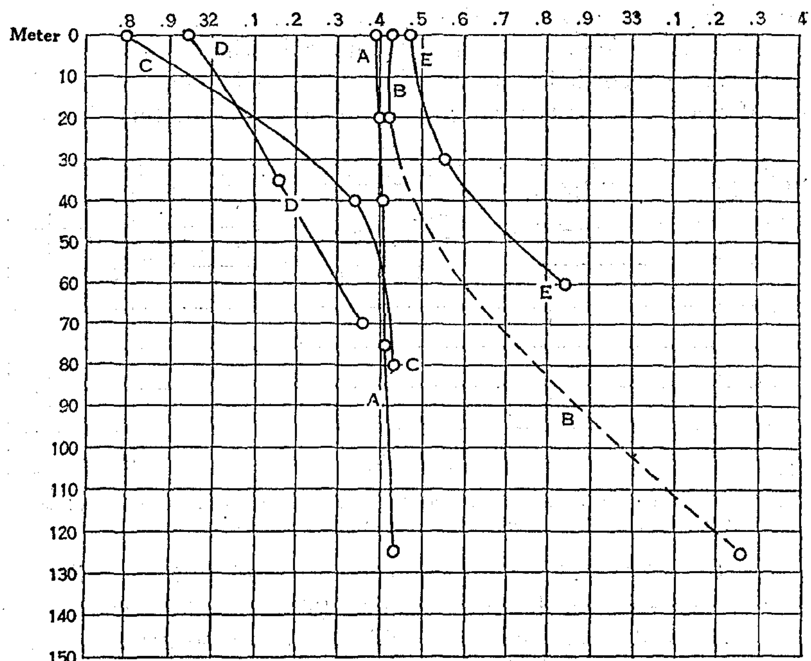

FIG. 123.—Vertical distribution of salinity off Penobscot Bay. A, March 4, 1920 (station 20057); B, April 10, 1920 (station 20097); C, May 12, 1915 (station 10276): D, June 14, 1915 (station 10287); E, October 9, 1915 (station 10329)

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]

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

[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).

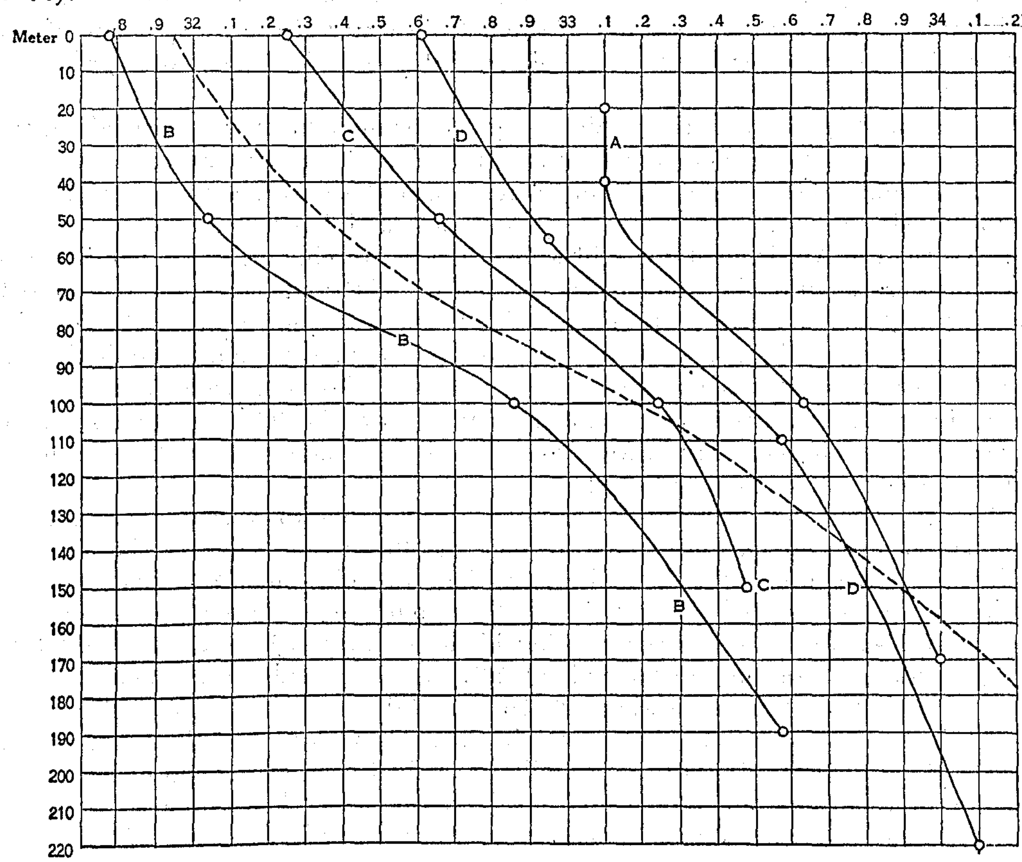

FIG. 124.—Vertical distribution of salinity in the eastern side of the basin of the Gulf of Maine on March 23, 1920 (A, station 20086); May 6, 1915 (B, station 10270); May 29, 1919 (broken curve, ice patrol station 37); June 19, 1915 (C, station 10289); and August 12, 1913 (D, station 10093)

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]

[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

[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.

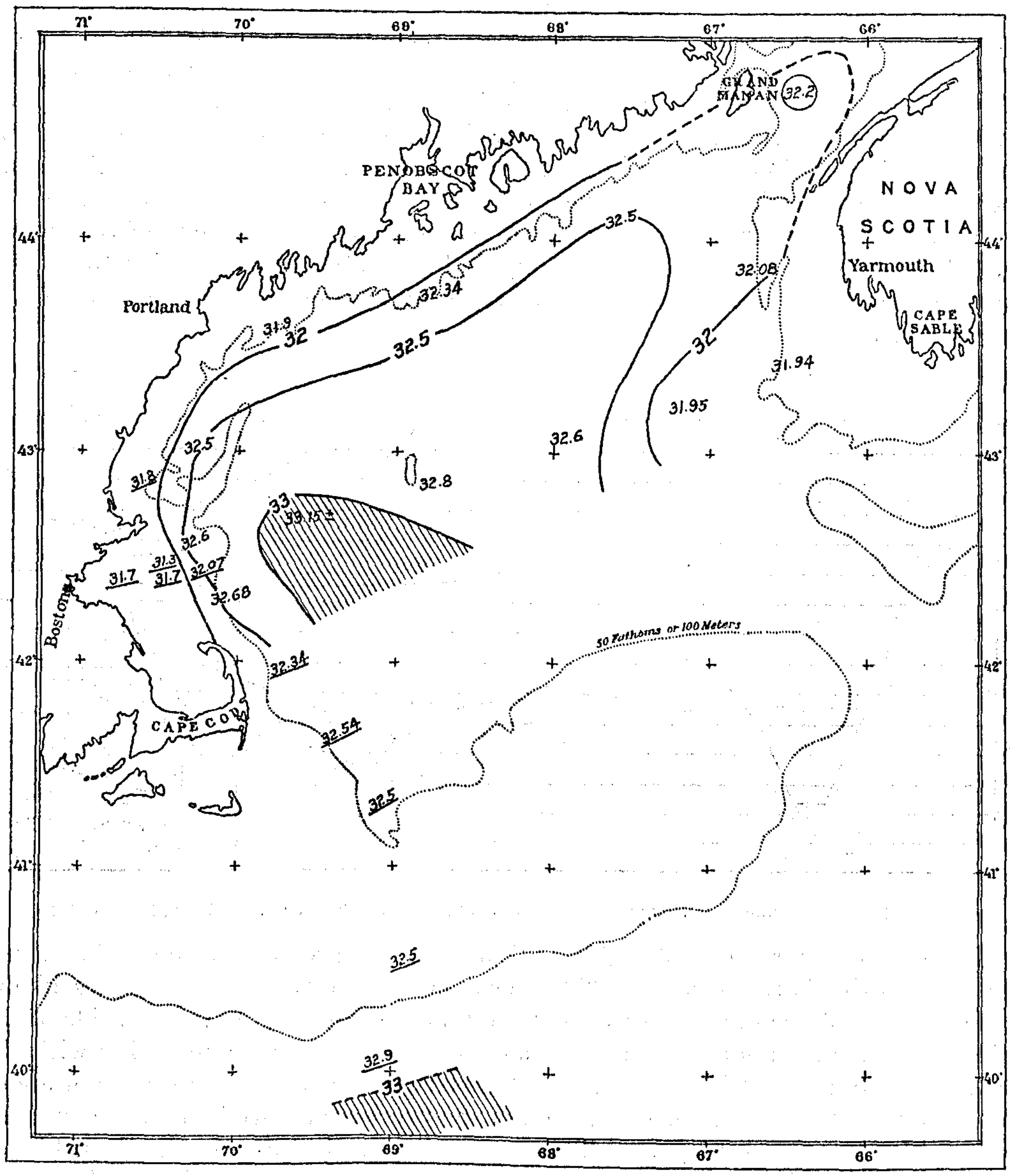

FIG. 125.—Salinity at a depth of 40 meters, May 4 to 14, 1915 (plain figures), combined with May 4 to 17, 1920 (underlined figures). The encircled figure in the Bay of Fundy is for May 4, 1917, from Mavor (1923). Dotted curves are assumed

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.

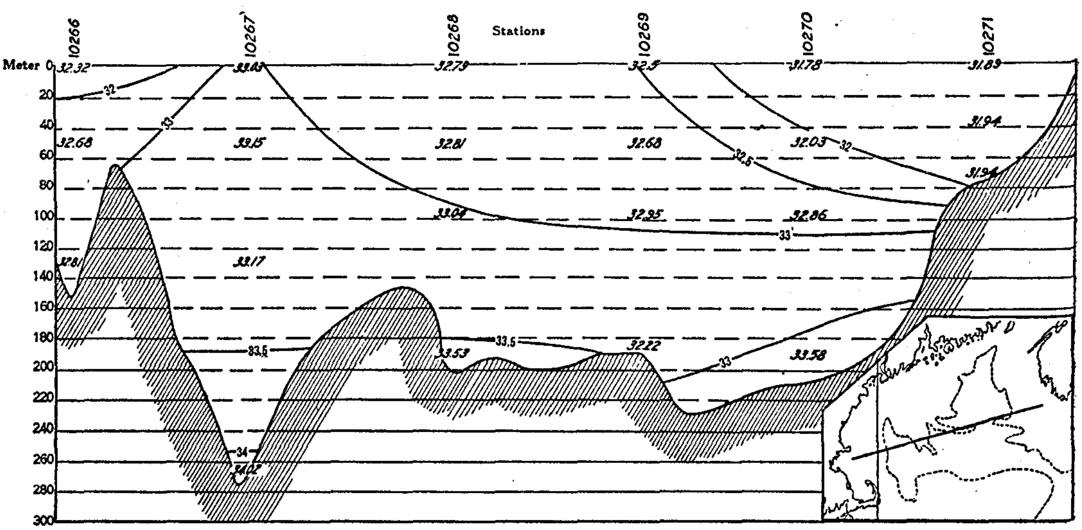

FIG. 126.—Salinity profile running eastward from the mouth of Massachusetts Bay to German Bank, May 4 to 7, 1915

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

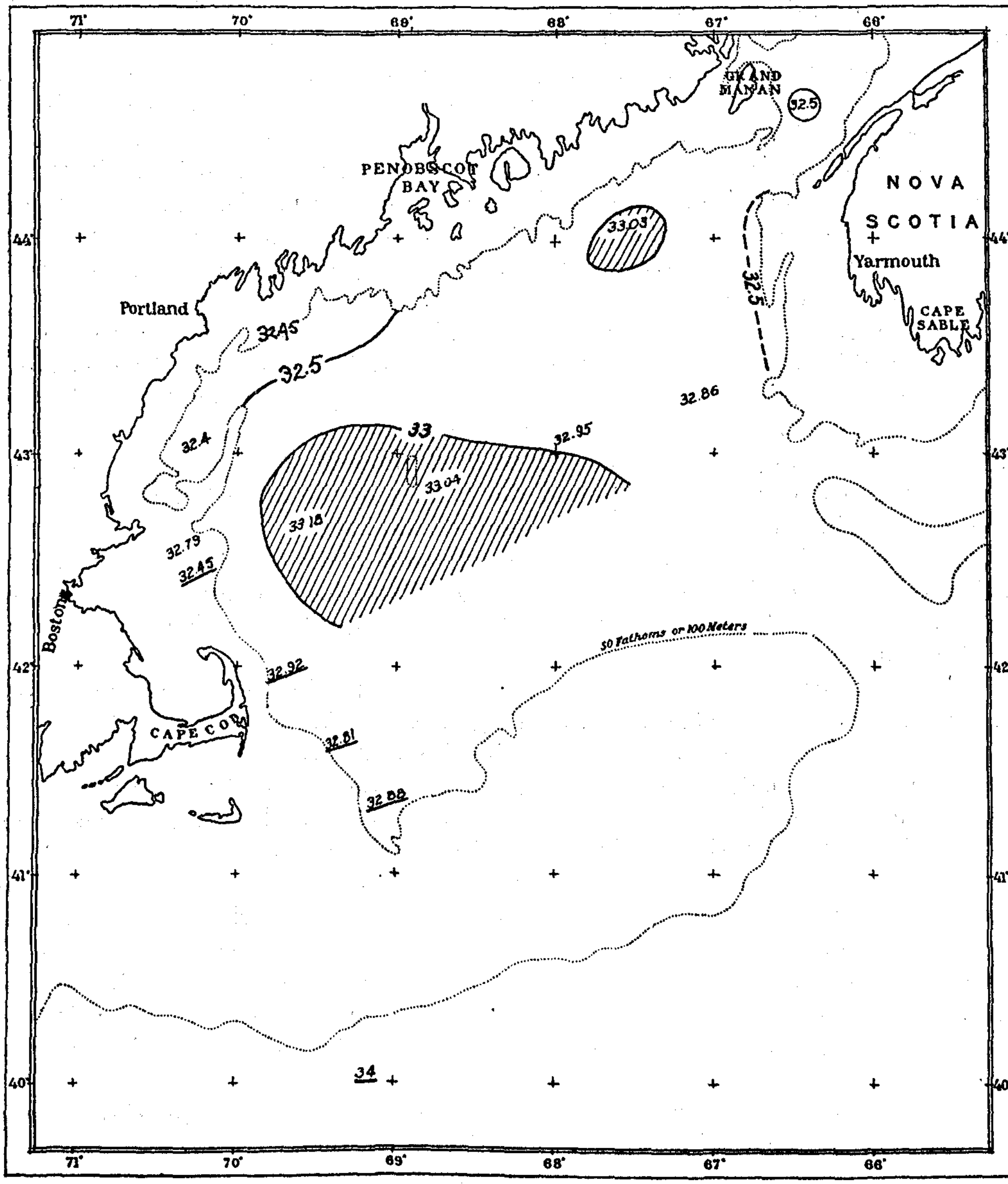

FIG. 127.—Salinity at a depth of 100 meters, May 4 to 14, 1915 (plain figures), combined with May 4 to 17, 1920 (underlined figures). The encircled figure in the Bay of Fundy is for May 4, 1917, from Mavor (1923)

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) 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.

[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

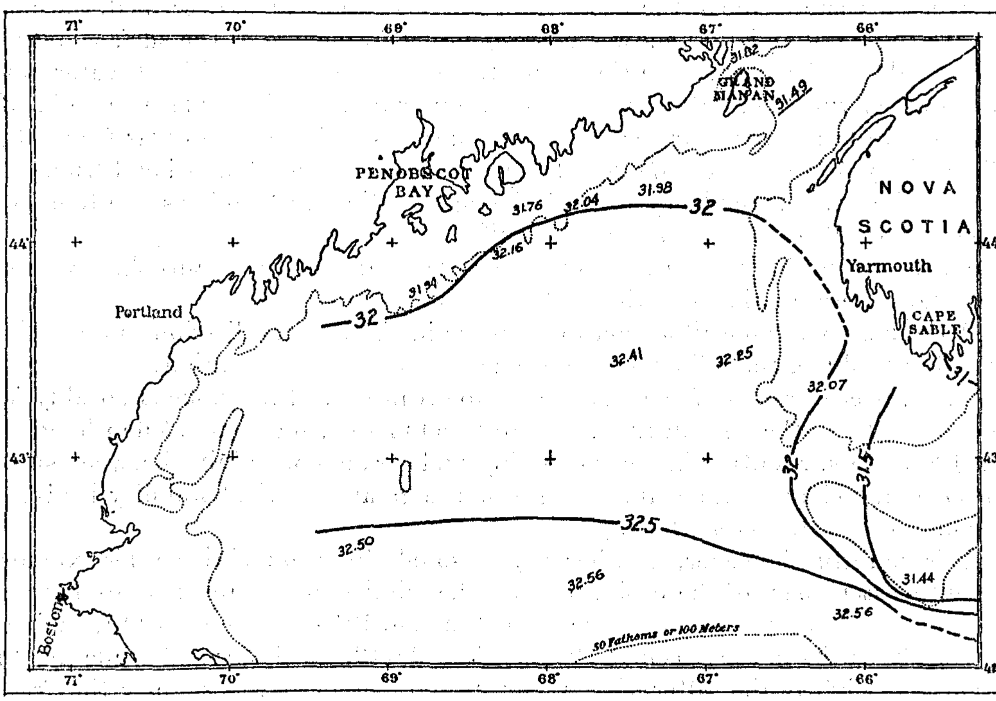

FIG. 128.—Surface salinity of the eastern and central parts of the Gulf of Maine, June, 1915

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.

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 apparent 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

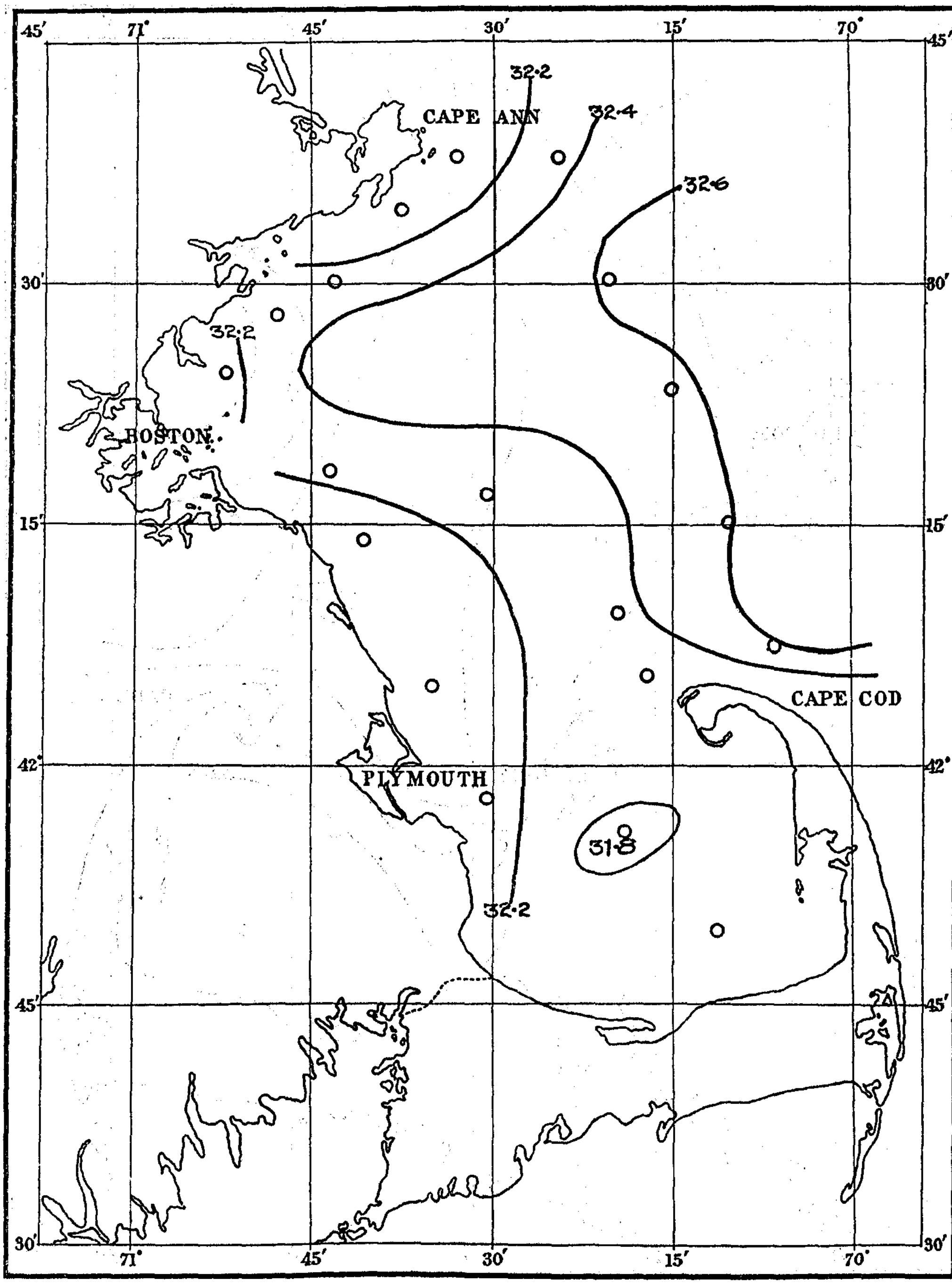

FIG. 129.—Salinity of Massachusetts Bay at the surface, June 16 to 17, 1925

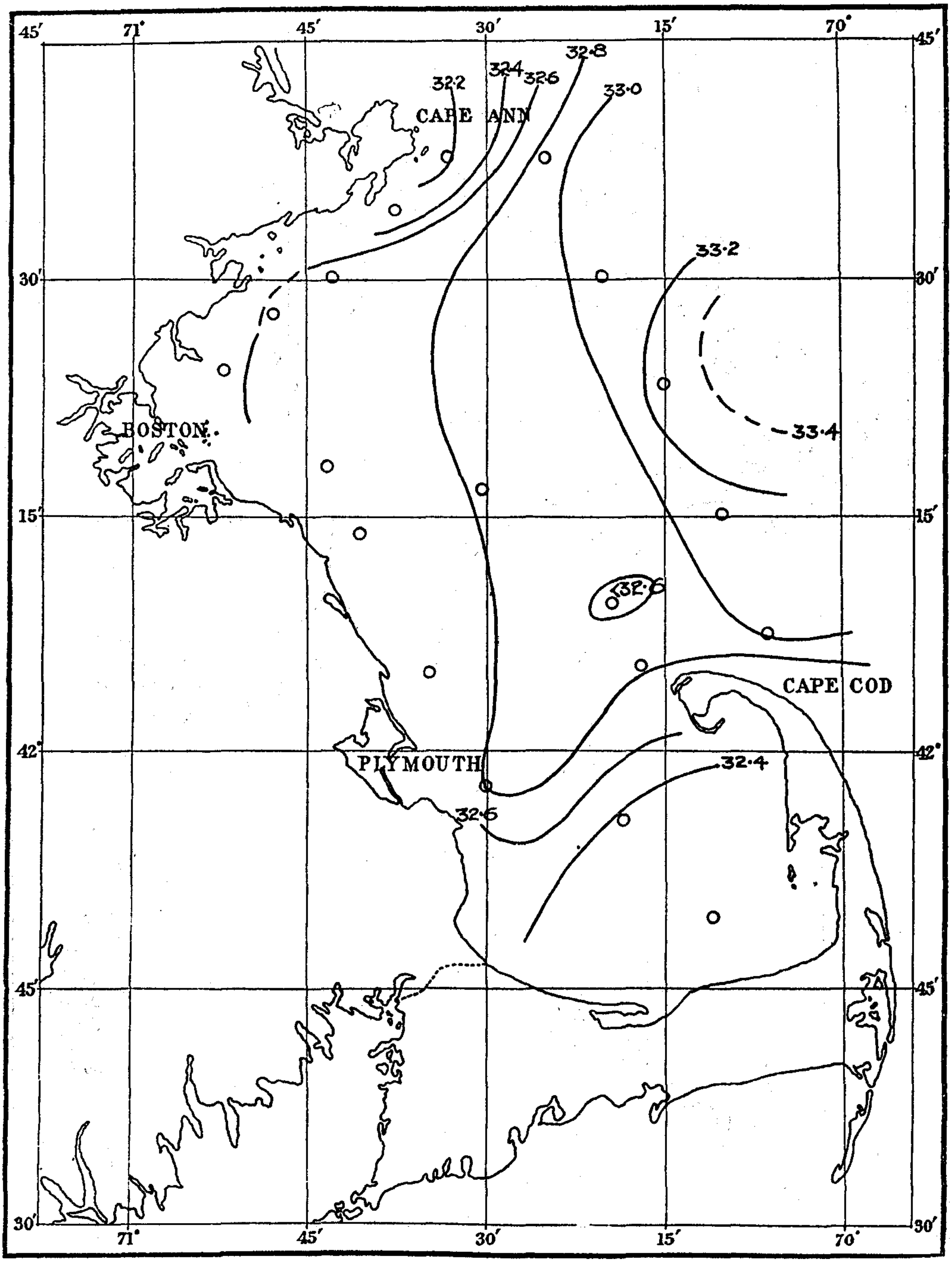

FIG. 130.—Salinity of Massachusetts Bay at 20 meters, June 16 to 17, 1925

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

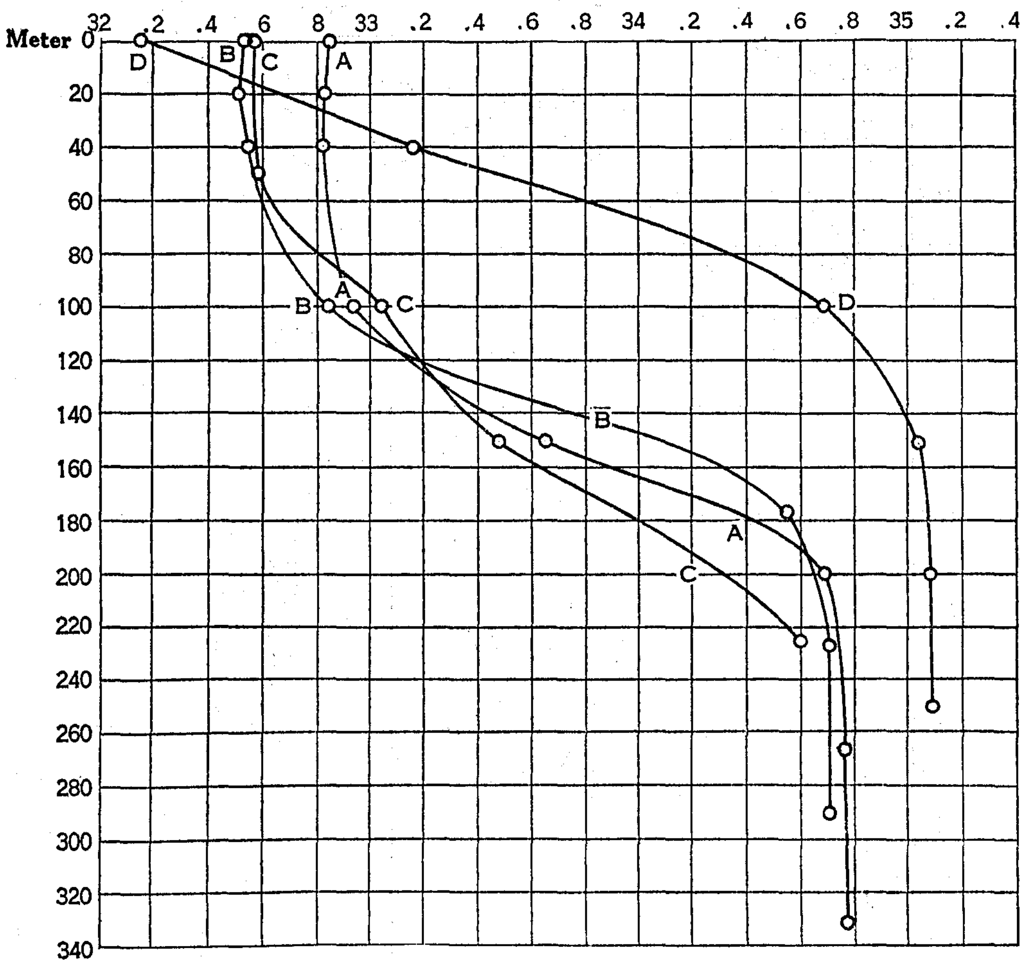

FIG. 131.—Vertical distribution of salinity in the southeastern part of the basin of the gulf. A, March, 1920 (station 20064); B, April, 1920 (station 20112); C, June, 1915 (station 10298); D, July, 1914 (station 10225)

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).

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

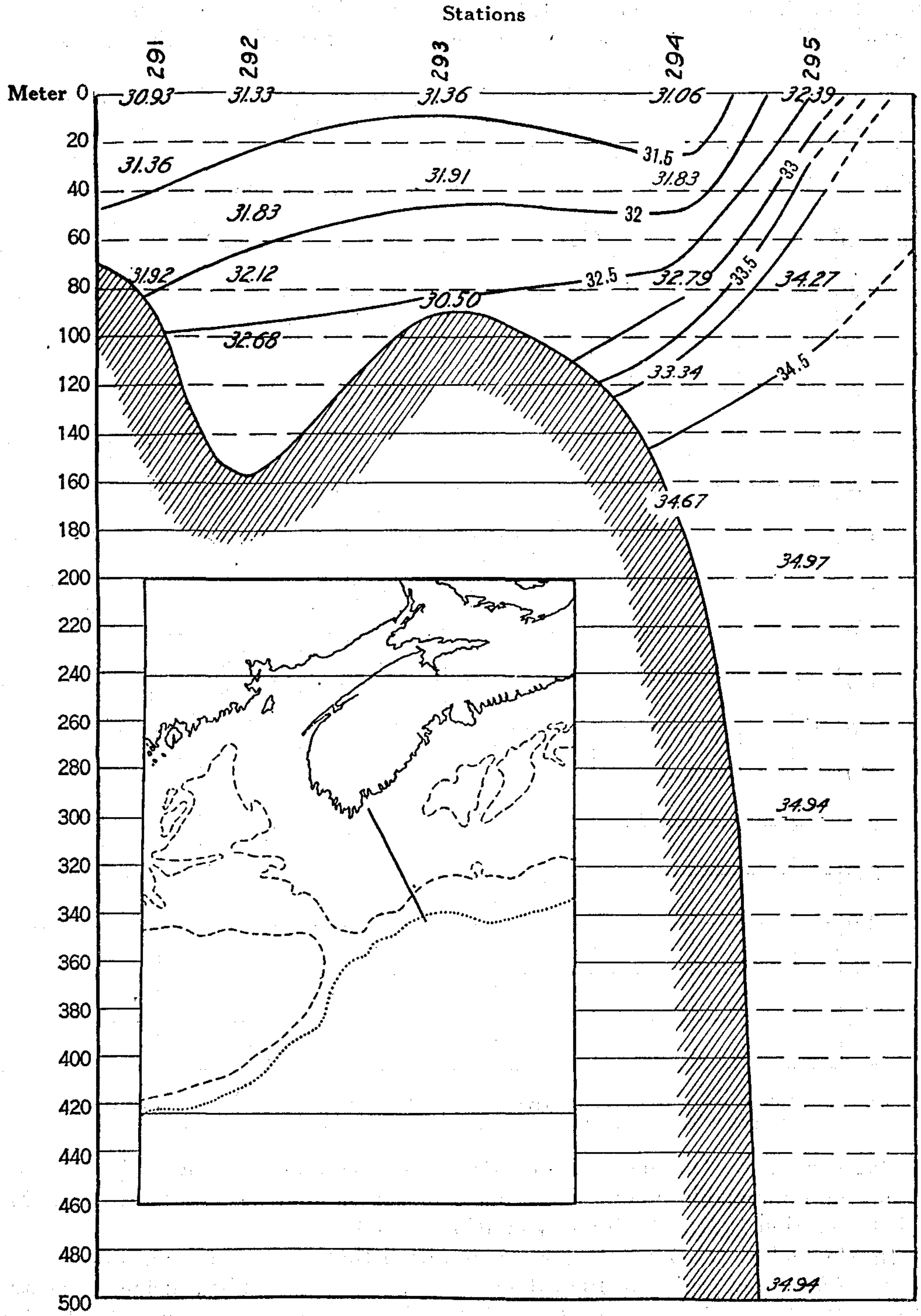

FIG. 132.—Salinity profile running southeastward from the offing of Shelburne, Nova Scotia, to the continental slope, June 23 to 24, 1915 (stations 10291 to 10295). Bottom value at station 10293 should read 32.50

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,

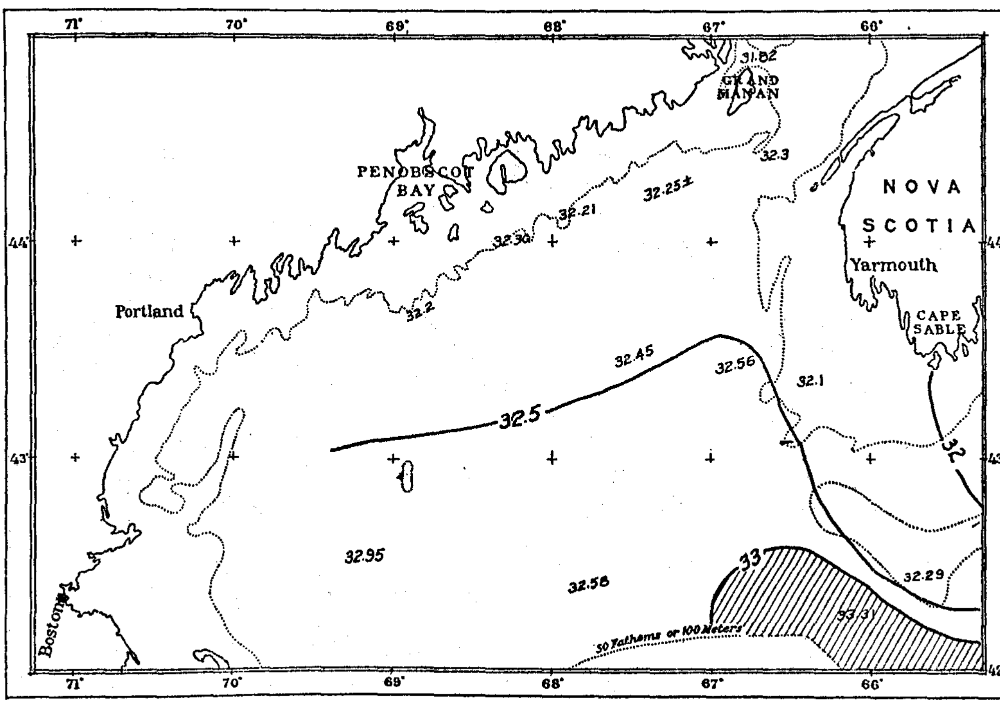

FIG. 133.—Salinity at a depth of 40 meters, last half of June, 1915

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).

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

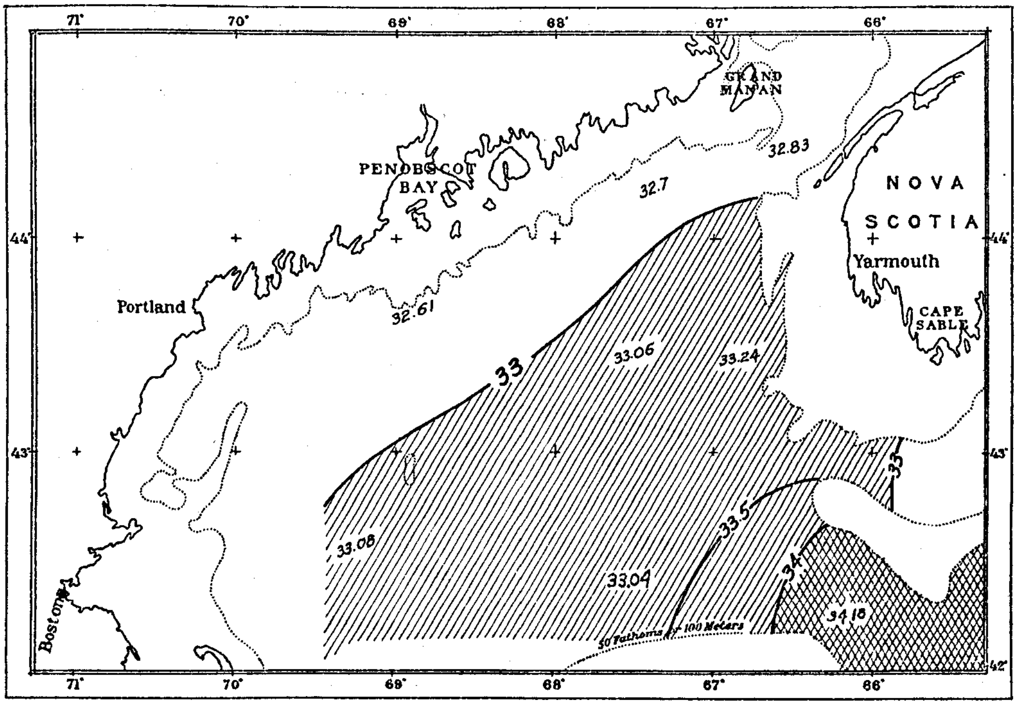

FIG. 134.—Salinity at a depth of 100 meters, last half of June, 1915

same sort was registered in the bottom of the open basin, as illustrated by the following tables:

Salinities (per mille) at 175 meters

Date	Northeastern corner	Eastern side	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), suggest 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.[95]

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.

[95] 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-

[96] Both taken with the same instrument.

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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

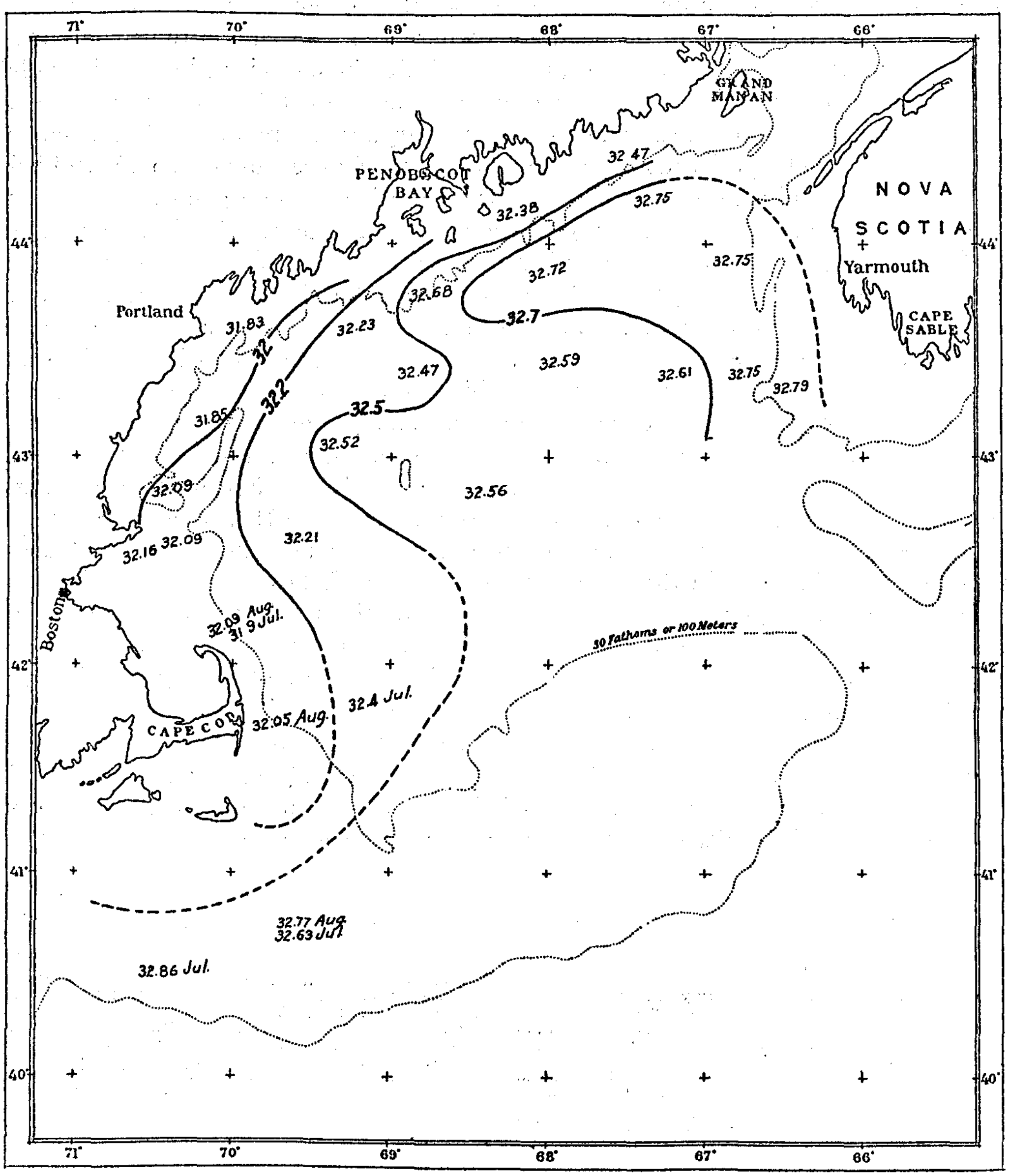

FIG. 135.—Salinity at the surface, August, 1913

10031), 32.75 to 32.79 per mille in 1913 (stations 10094 to 10097), and 33.06 per mille in 1914.

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 salini-

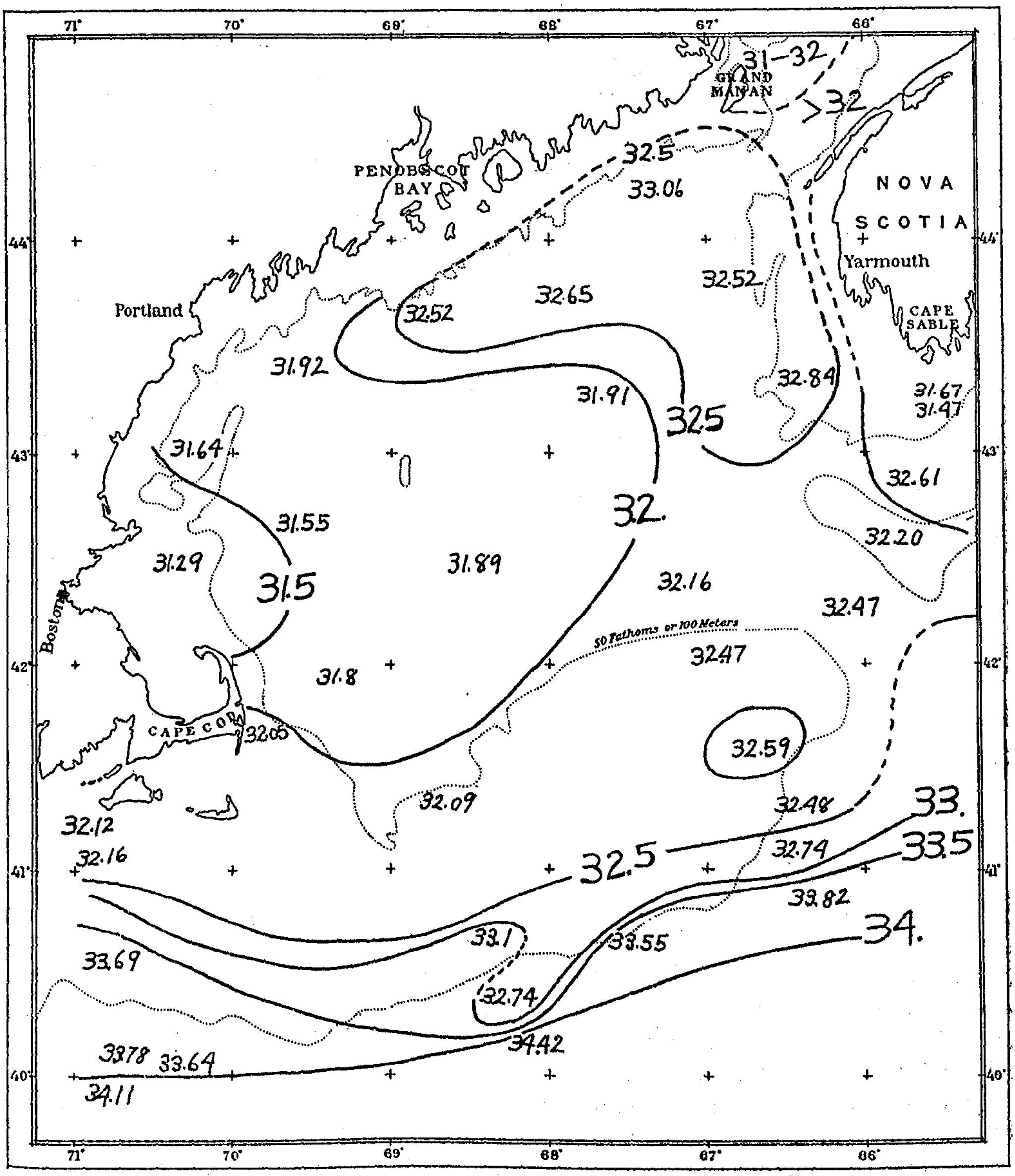

FIG. 136.—Salinity at the surface, July to August, 1914. For 32.61 in the northern channel read 32.01

ties 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 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,

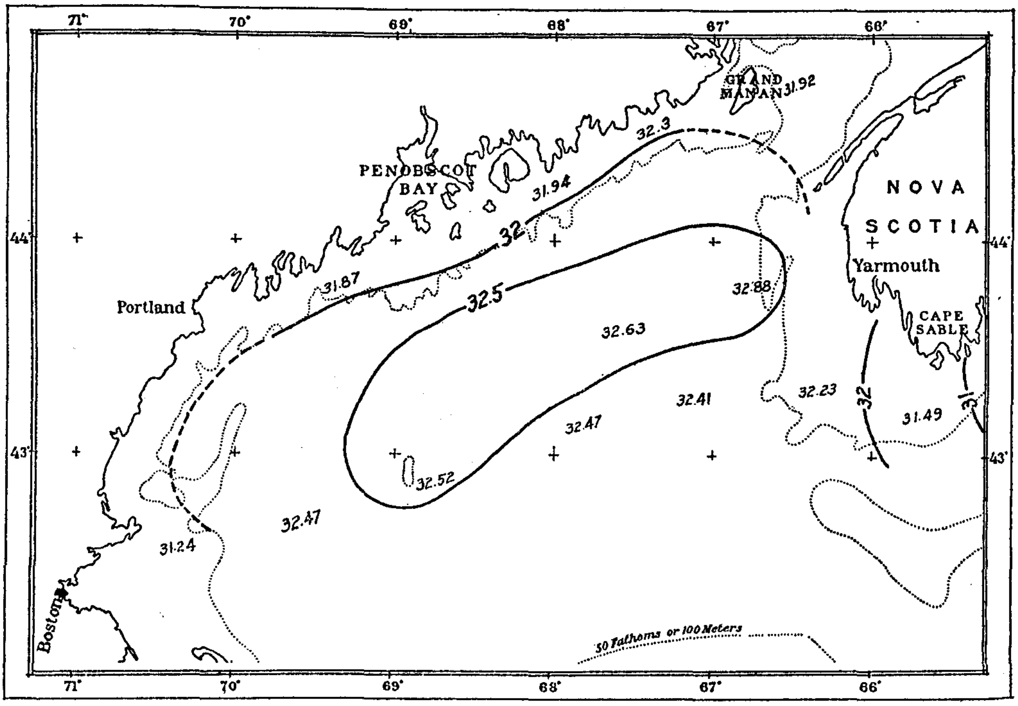

FIG. 137.—Salinity at the surface, August to September, 1915

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).

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

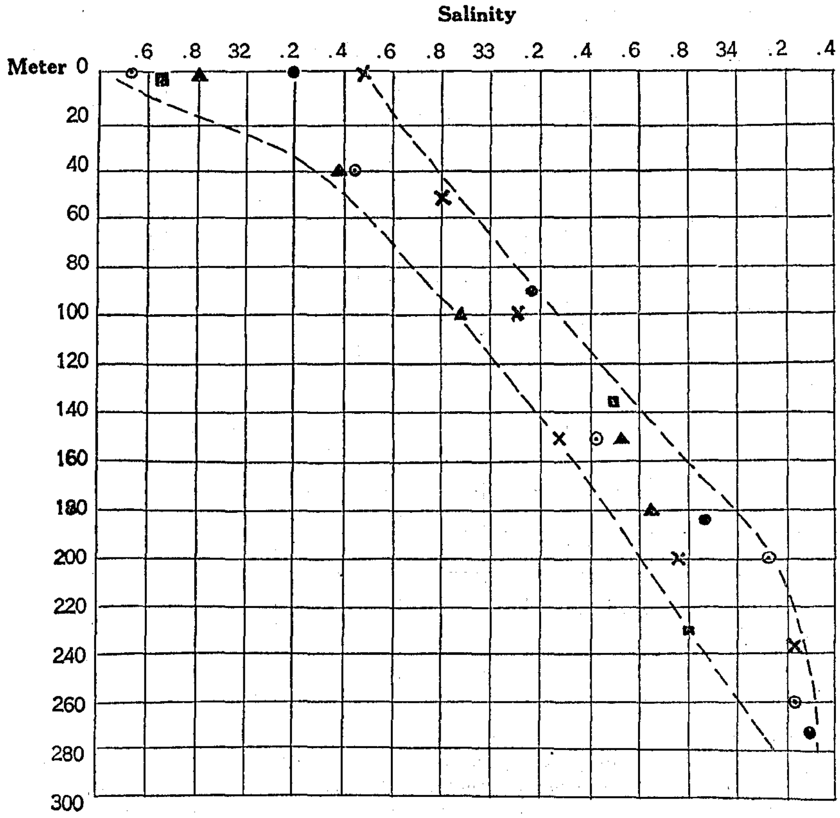

FIG. 138.—Vertical distribution of salinity in the western side of the basin, in the offing of Cape Ann, in July and August of different years. ●, August 9, 1913 (station 10088); ⊙, August 22, 1914 (station 10254); ▲, August 23, 1914 (station 10256); X, August 31, 1915 (station 10307). The broken curve marks the approximate limits to annual variation

mille in July or August, with a maximum vertical range of about 1 per mille in the Massachusetts Bay region within these depth limits.

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

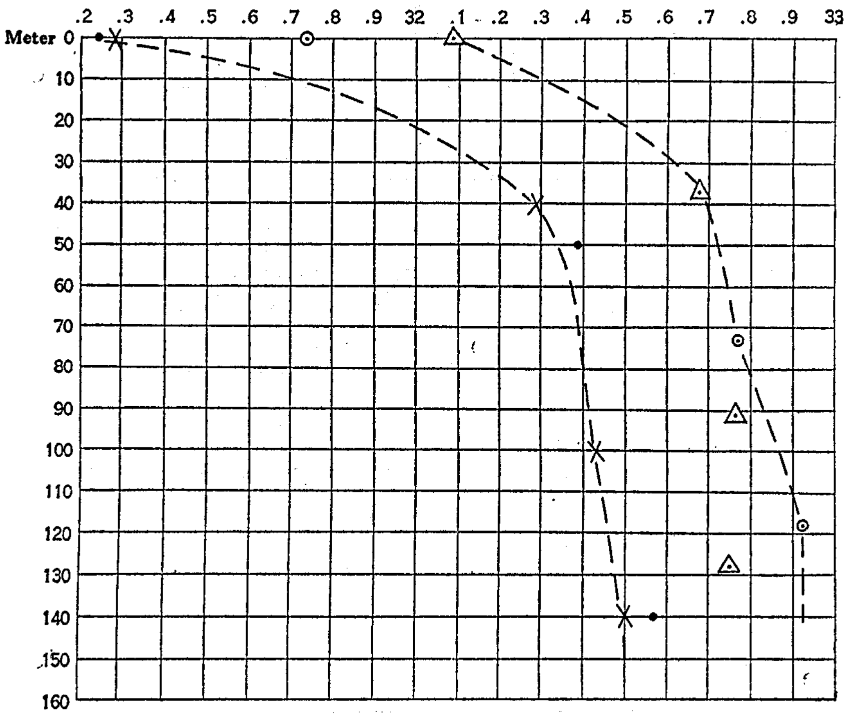

FIG. 139.—Vertical distribution of salinity in the deep bowl off Gloucester in July and August of different years. ⊙, July 10, 1912 (station 10002); △, August 9, 1913 (station 10089); ×, August 22, 1914 (station 10253); ●, August 31, 1915 (startion 10306). The broken curves mark the approximate limits of annual variation

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.

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	32.70	0.22
		64	32.92	
10095	Aug. 12, 1913	0	32.75	.19
		55	32.94	
10244	Aug. 12, 1914	0	32.84	.06
		55	32.90	
10311	Sept. 2, 1915	0	32.23	.33
		65	32.56	

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

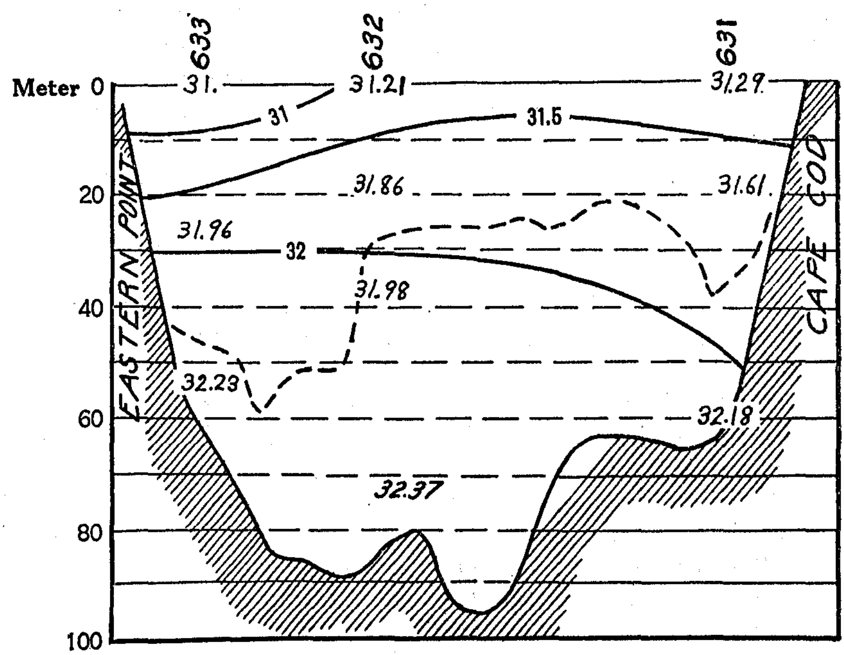

FIG. 140.—Salinity profile crossing the mouth of Massachusetts Bay, Gloucester to Cape Cod, just west of Stellwagen Bank, August 22, 1922. The broken curve is the contour of the bank

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 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

[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

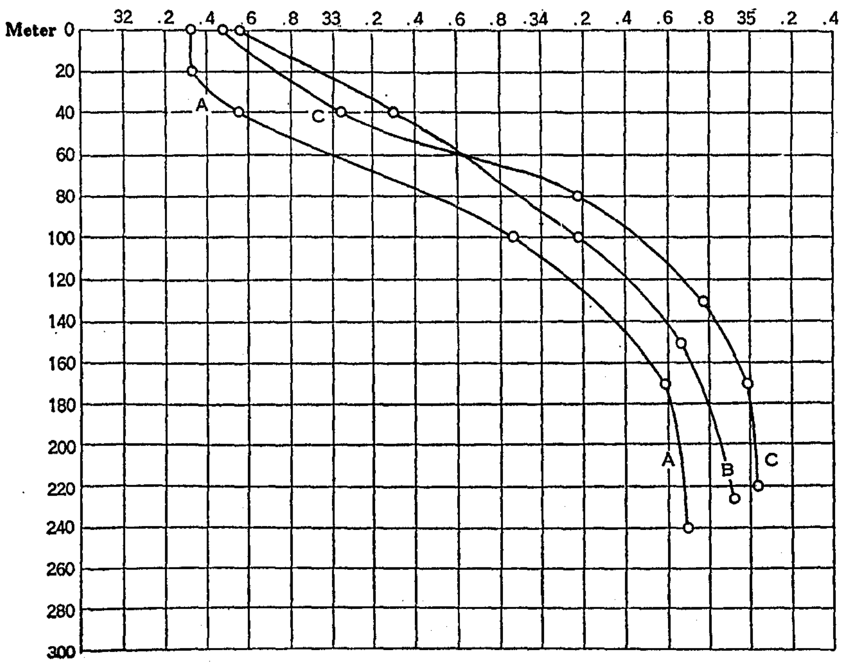

FIG. 141.—Vertical distribution of salinity in the Eastern Channel. A, April 16, 1920 (station 20107); B, June 25, 1915 (station 10297); C, July 24, 1914 (station 10227)

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).

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

[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[99] 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

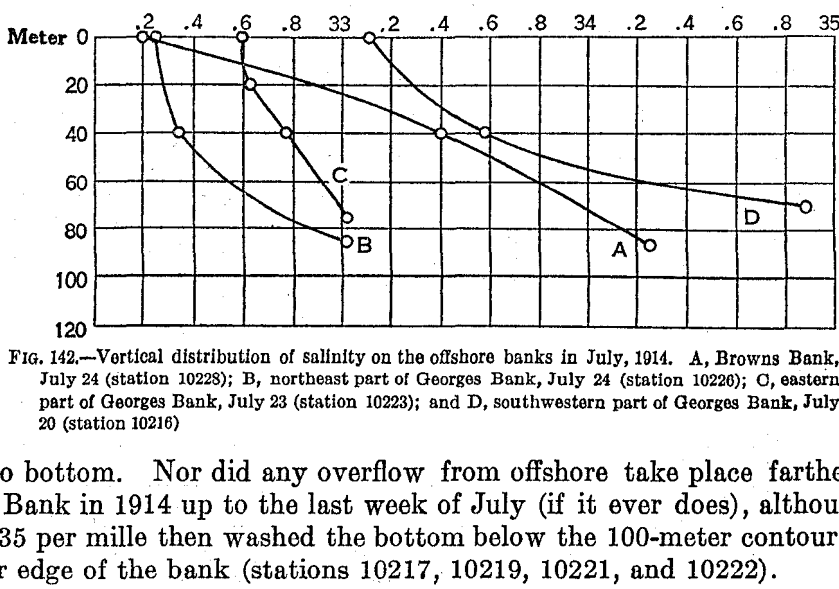

FIG. 142.—Vertical distribution of salinity on the offshore banks in July, 1914. A, Browns Bank, July 24 (station 10228); B, northeast part of Georges Bank, July 24 (station 10226); C, eastern part of Georges Bank, July 23 (station 10223); and D, southwestern part of Georges Bank, July 20 (station 10216)

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).

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

[99] 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

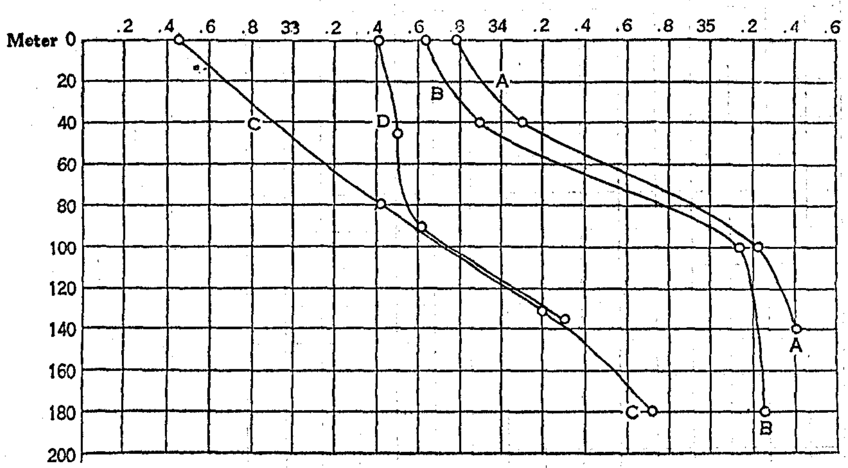

FIG. 143.—Vertical distribution of salinity on the outer part of the continental shelf off Nantucket and Marthas Vineyard. A, August, 1914 (station 10260); B, August 26, 1914 (station 10262); C, July 24, 1916 (station 10351); D, July 10, 1913 (station 10061)

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.

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

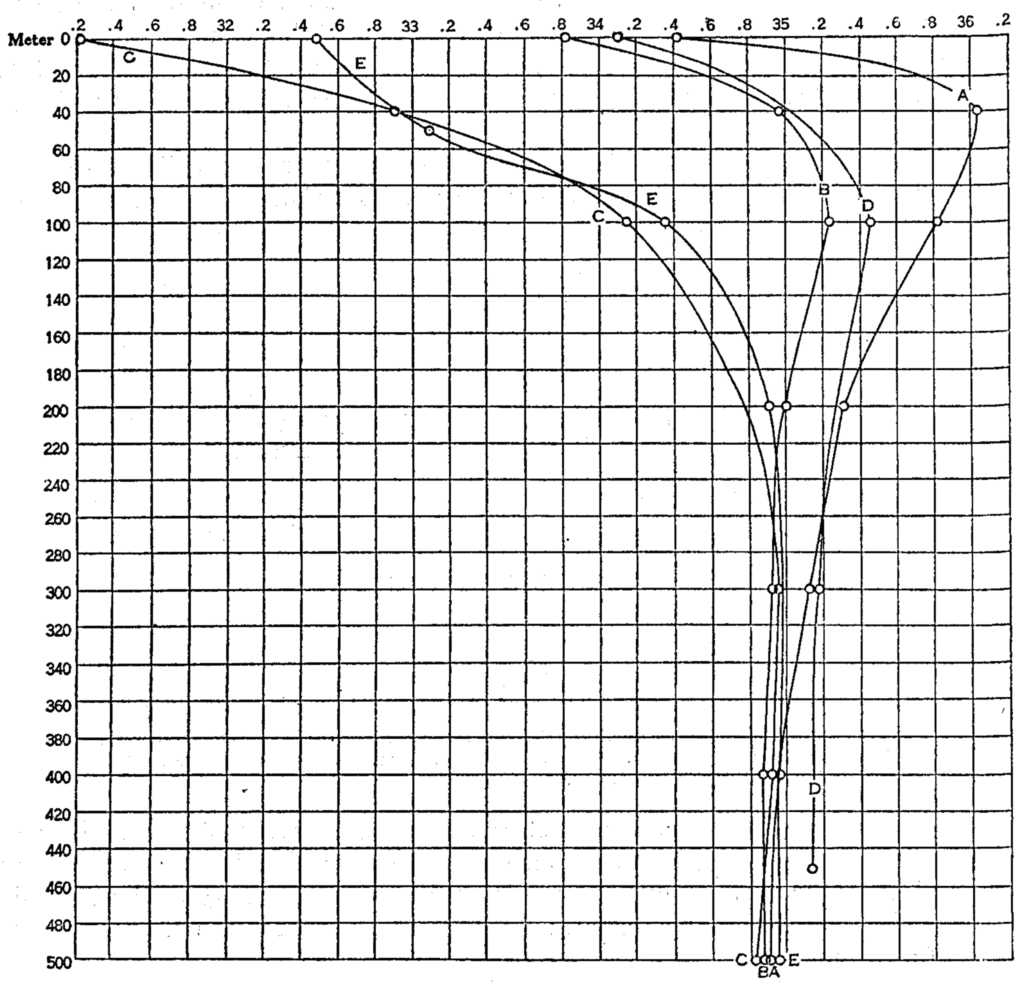

FIG. 144.—Vertical distribution of salinity along the continental slope abreast of the Gulf of Maine in summer. A, southwest slope of Georges Bank, July 21, 1914 (station 10218); B, southeast slope of Georges Bank, July 22, 1914 (station 10220); C, abreast of Shelburne, Novia Scotia, July 28, 1914 (station 10233); D, south of Marthas Vineyard, August 26, 1914 (station 10261); E, southwest slope of Georges Bank, July 24, 1916 (station 10352)

(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 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

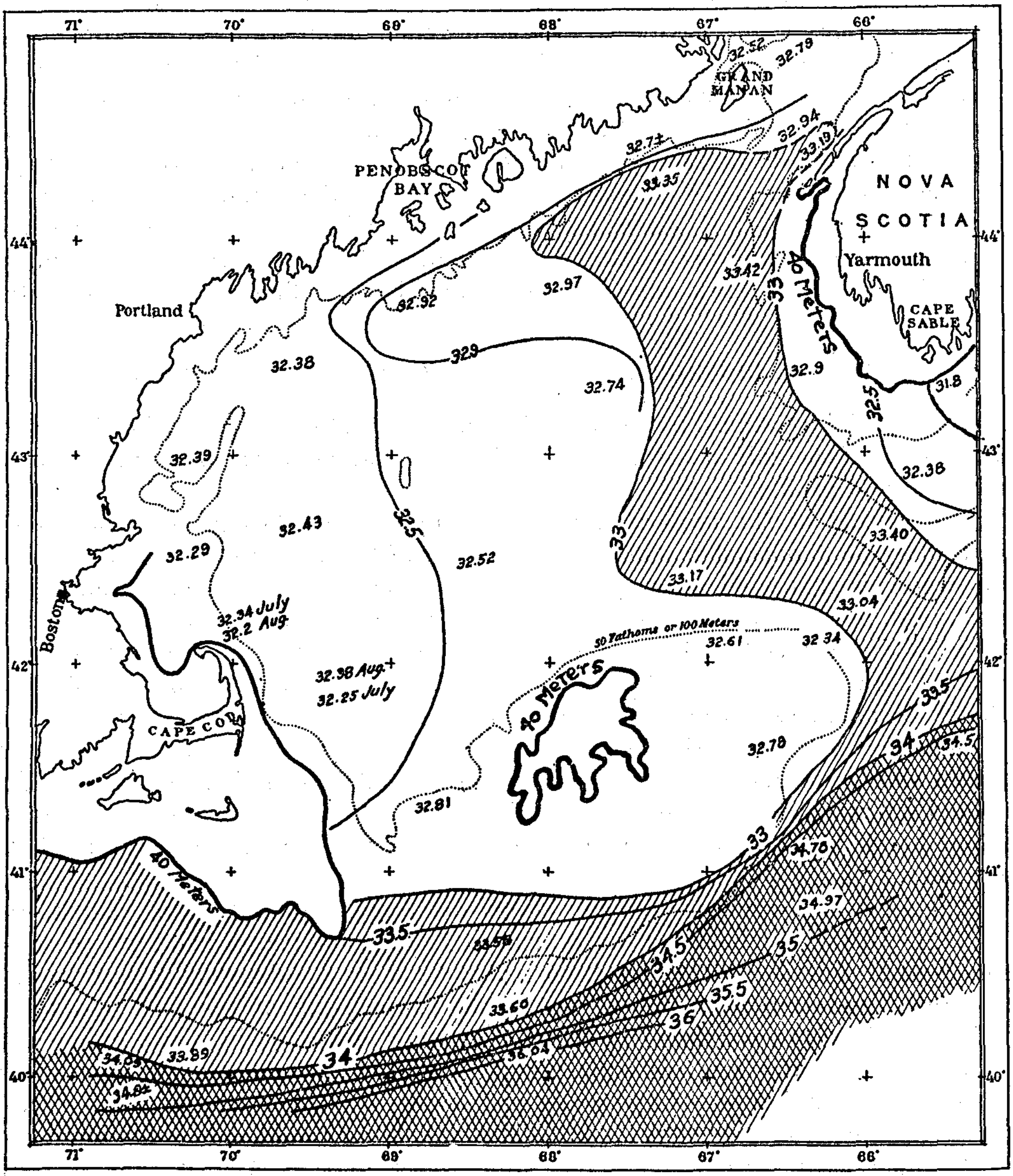

FIG. 145.—Salinity at a depth of 40 meters, July 19 to August 24, 1914

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.

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

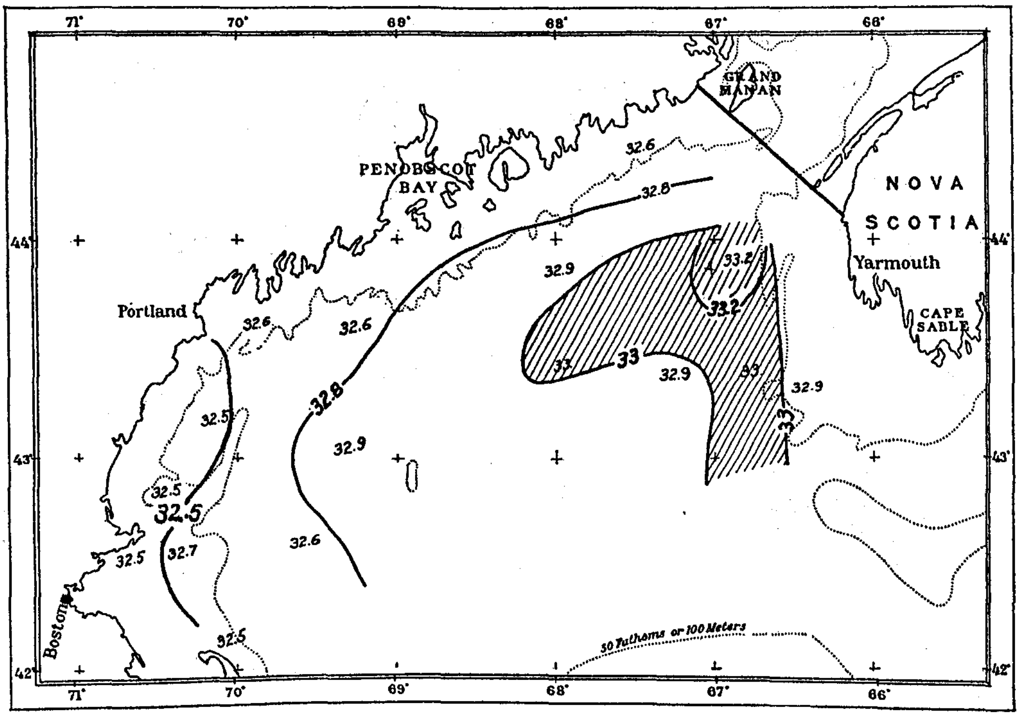

FIG. 146.—Salinity at a depth of 40 meters, August 5 to 20, 1913

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).

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

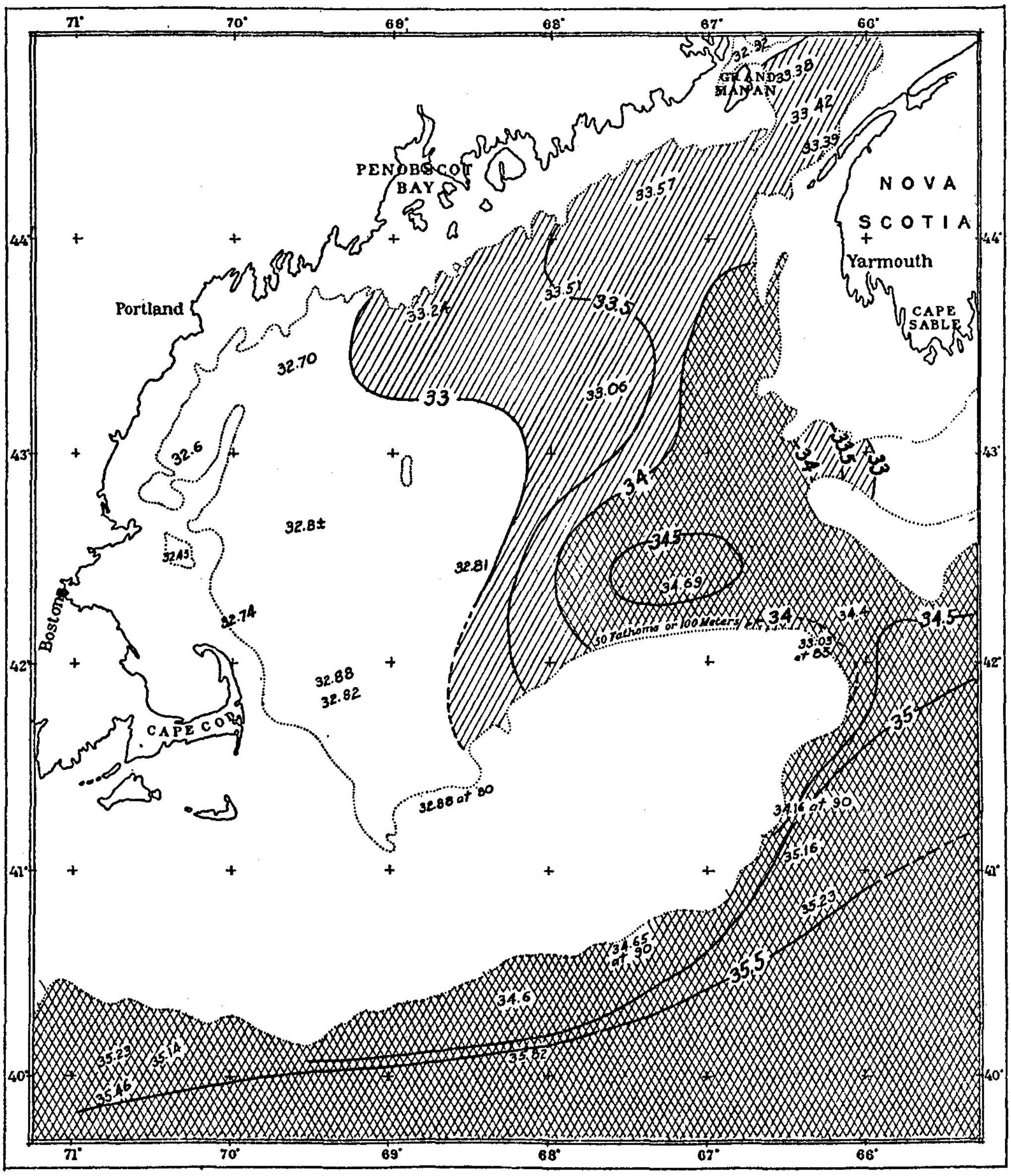

FIG. 147.—Salinity at a depth of 100 meters, July 19 to August 26, 1914. Bay of Fundy from Craigie

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 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

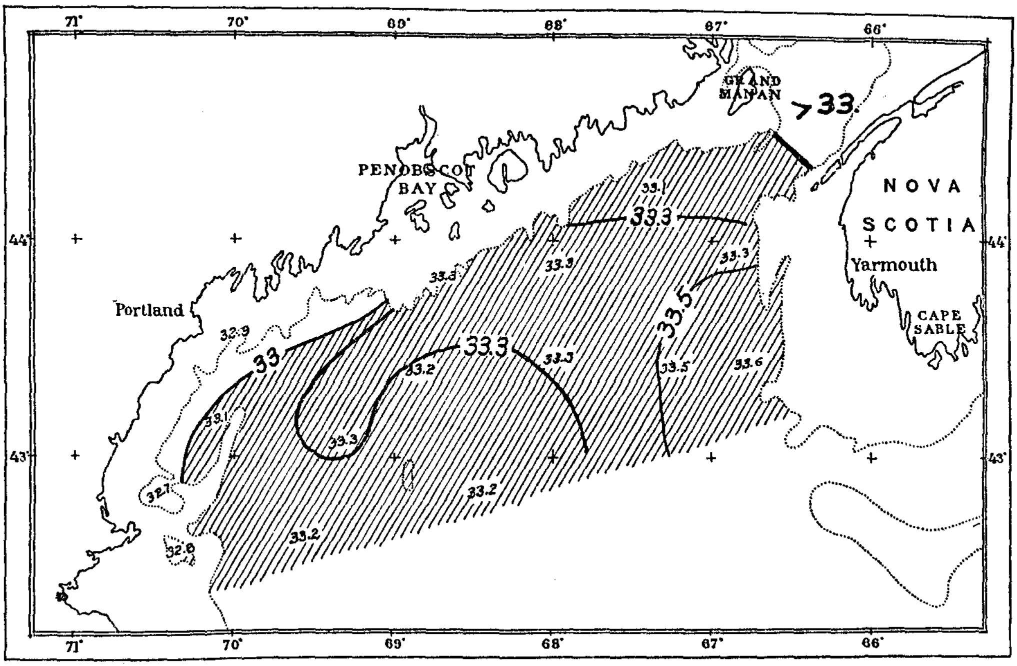

FIG. 148.—Salinity at a depth of 100 meters, August 5 to 20, 1913

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.

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

[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).

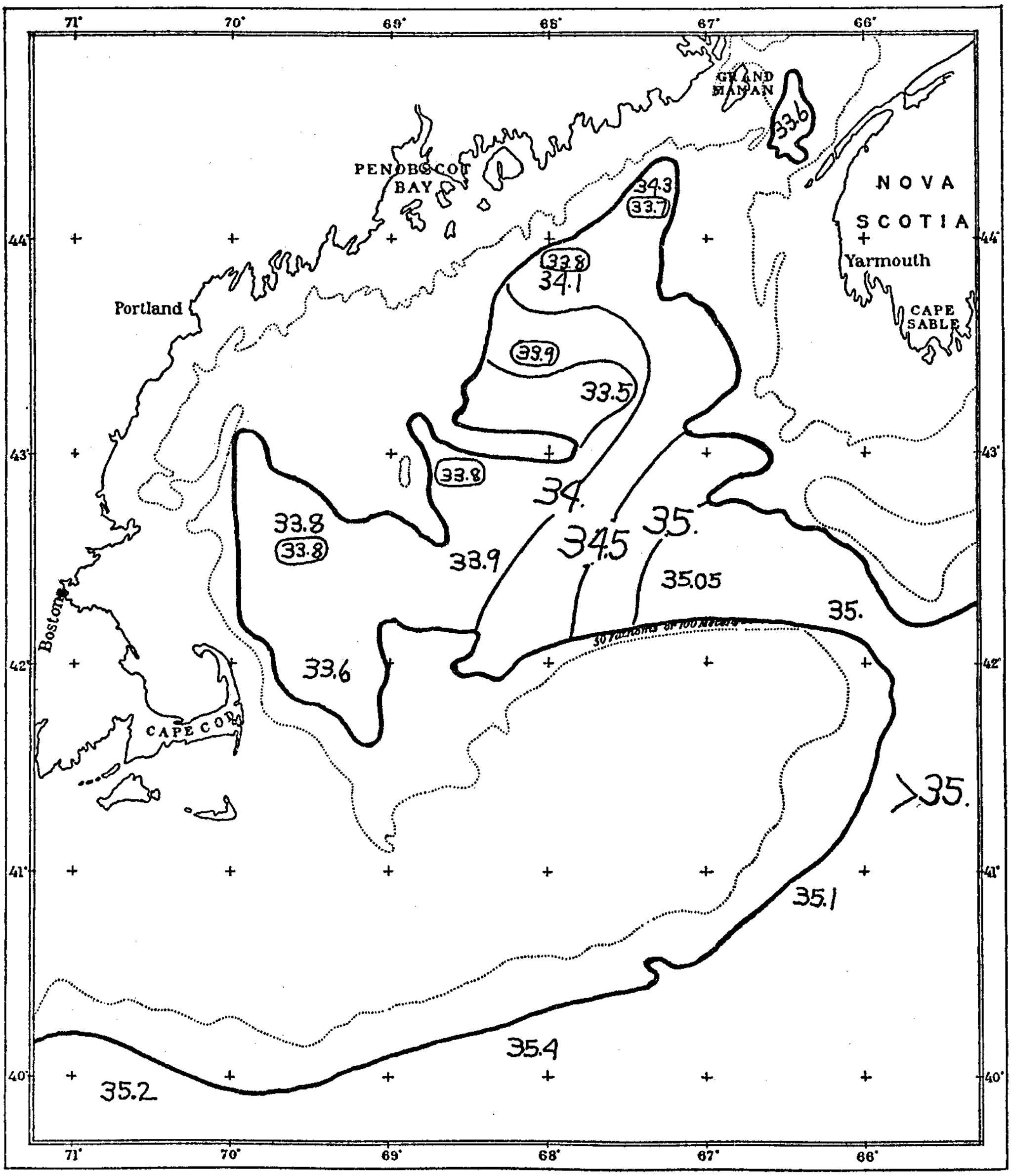

FIG. 149.—Salinity at a depth of 175 meters for August, 1913 (encircled figures), and for July 19 to August 26, 1914 (plain figures). Data for the Bay of Fundy from Craigie (1916a)

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

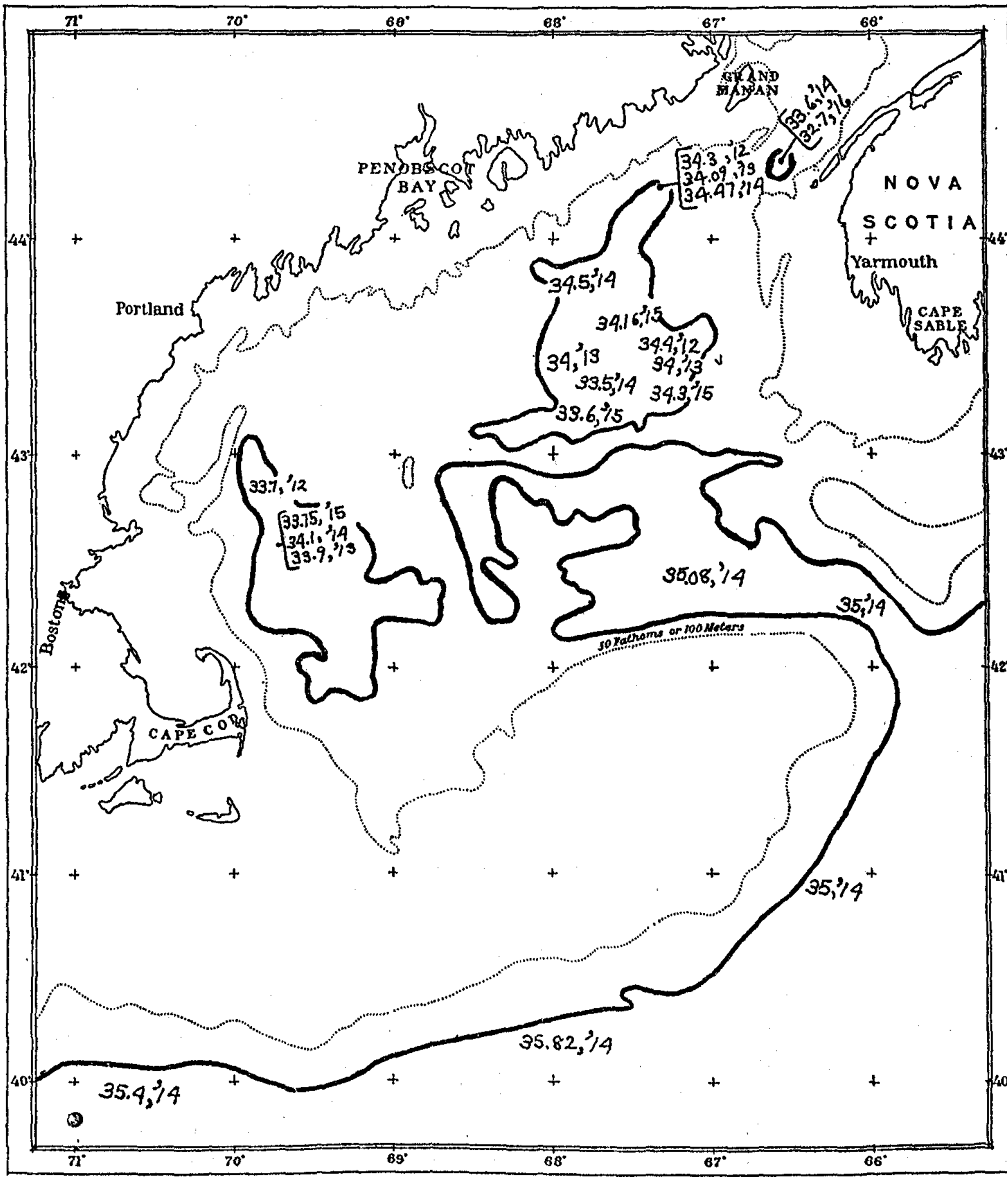

FIG. 150.—Salinity at a depth of 200 meters, July and August, 1912 to 1915

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.

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).

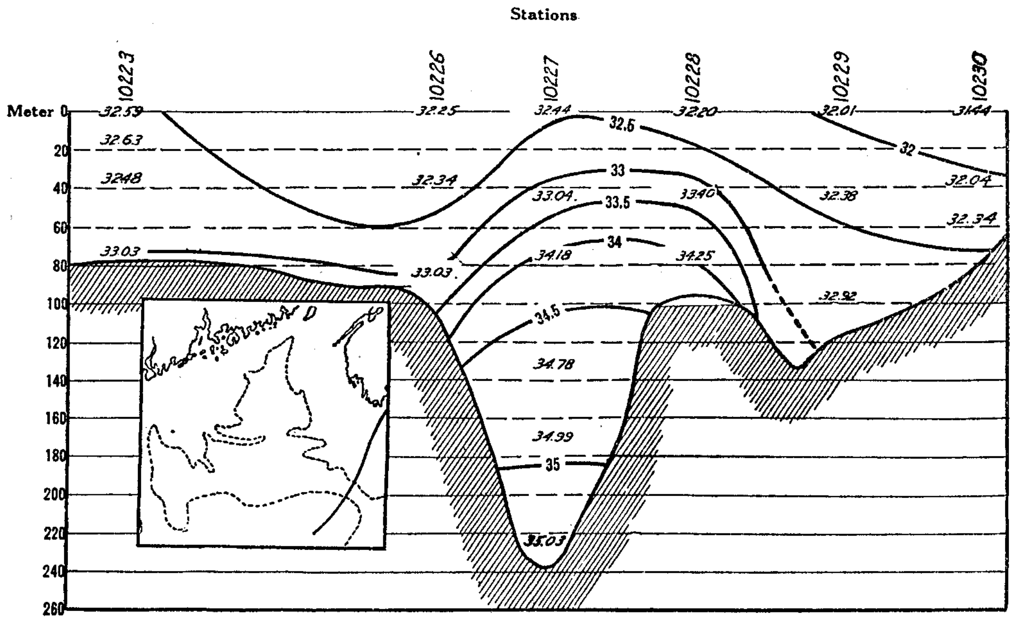

FIG. 151.—Salinity profile running from the eastern part of Georges Bank (stations 10223 and 10226) across the Eastern Channel (station 10227), Browns Bank (station 10228), and the Northern Channel (station 10229), to the offing of Cape Sable (station 10230), for July 23 to 25, 1914

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.

[3] 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

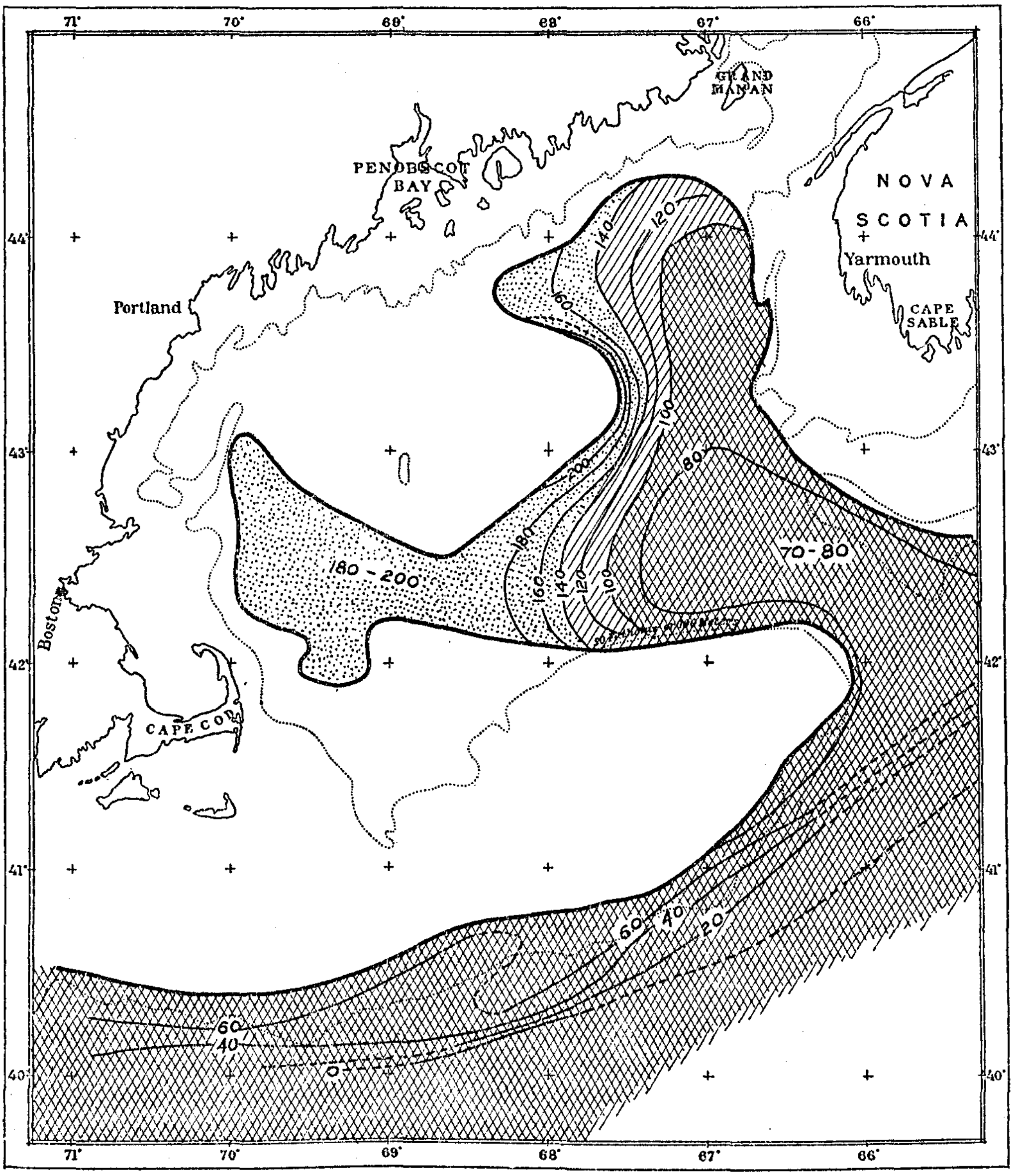

FIG. 152.—Depth below the surface of the isohalobath for 34 per mille, July to August, 1914

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).

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

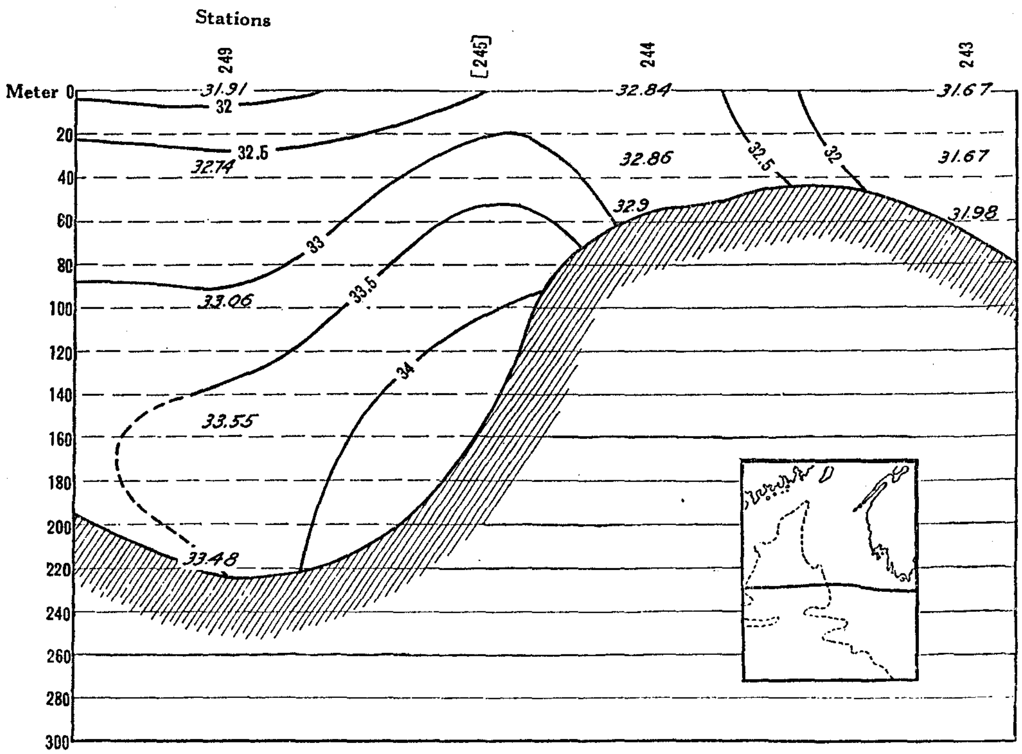

FIG. 153.—Salinity profile running eastward from the offing of Cape Sable (station 10243) toward the center of the Gulf of Maine (station 10249), for August 11 to 13, 1914

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.

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).

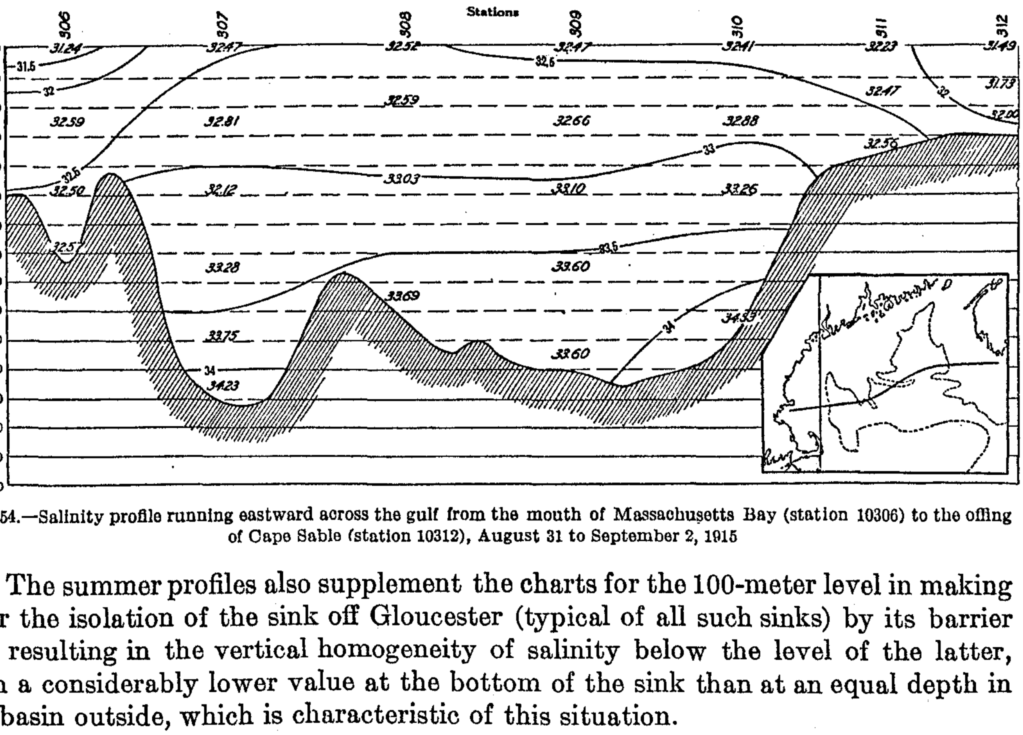

FIG. 154.—Salinity profile running eastward across the gulf from the mouth of Massachusetts Bay (station 10306) to the offing of Cape Sable (station 10312), August 31 to September 2, 1915

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

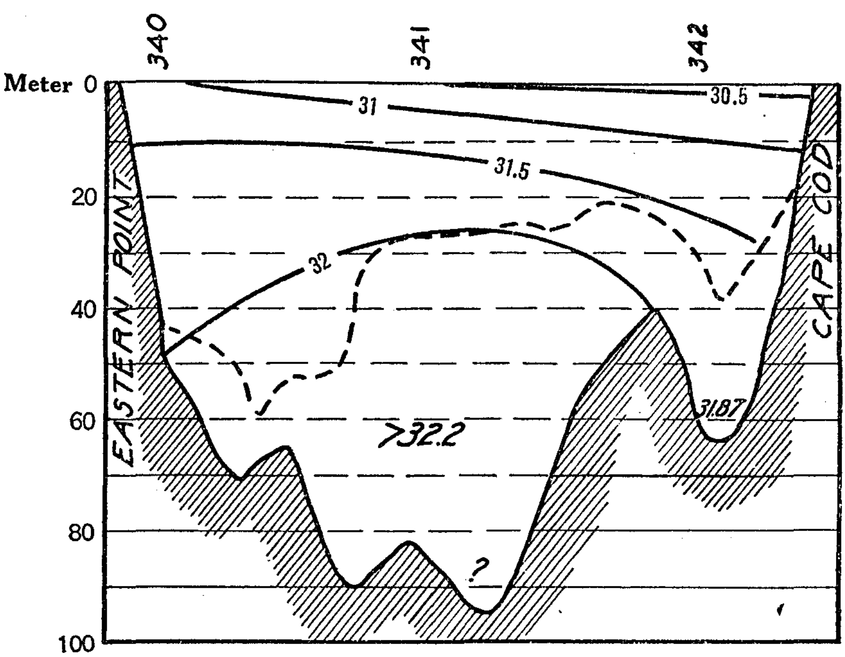

FIG. 155.—Salinity profile crossing Massachusetts Bay from the eastern point, Gloucester to Cape Cod, just inside Stellwagen Bank for, July 19, 1916. The broken curve gives the contour of the bank (stations 10340 to 10342)

the 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.

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

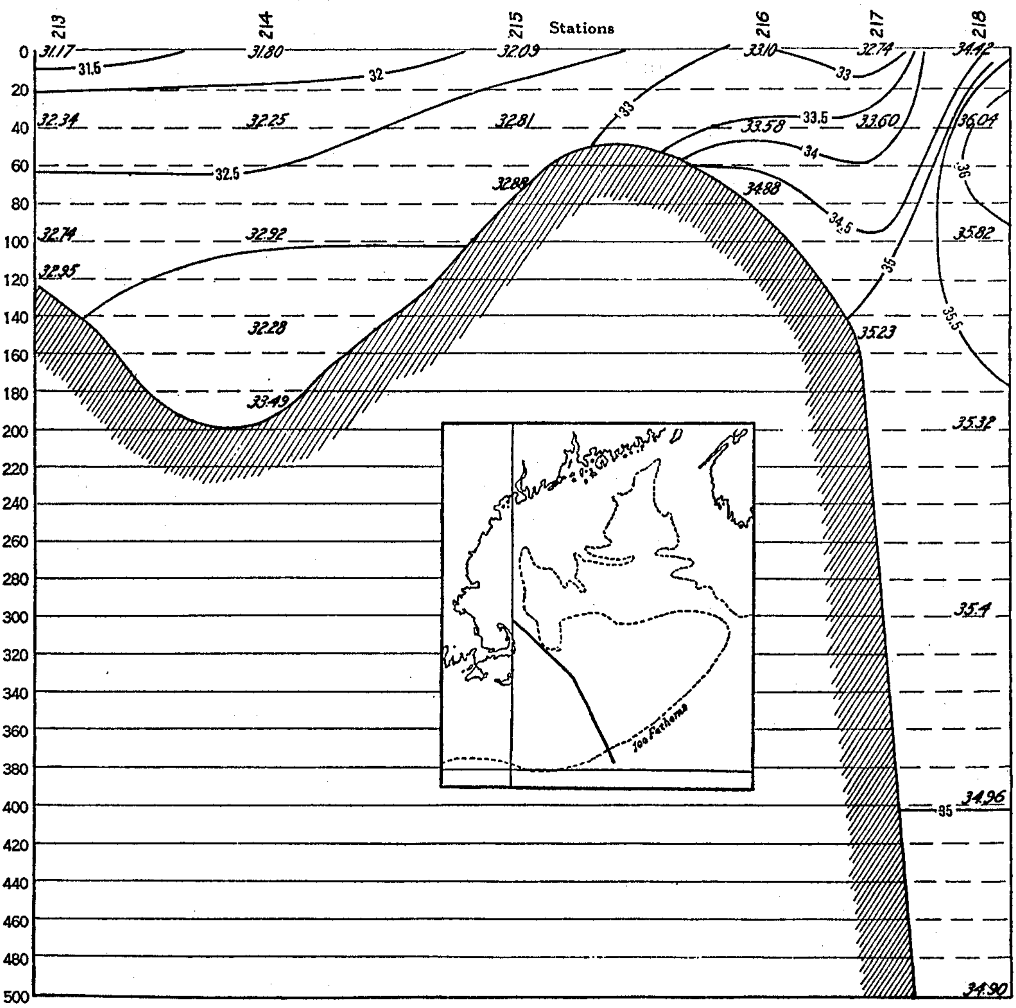

FIG. 156.—Salinity profile running from a station (10213) off northern Cape Cod, southward across the western end of Georges Bank (stations 10215 and 10217), to the continental slope (station 10218), July 19 to 21, 1914

(p. 842), thus accounting for the rarity of tropical planktonic animals and plants within the gulf (Bigelow, 1925).

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

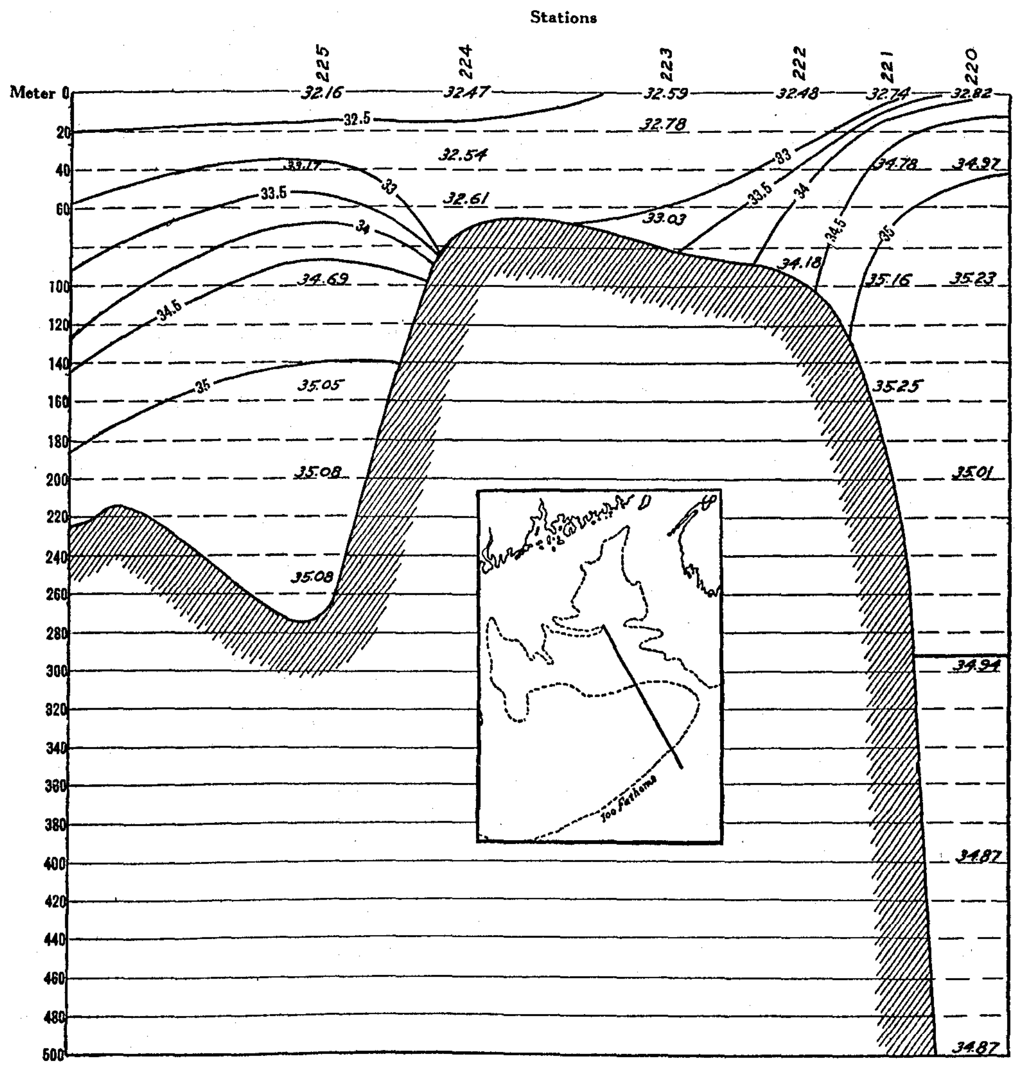

FIG. 157.—Salinity profile running from the southeastern part of the gulf (station 10225), southward across the eastern end of Georges Bank (stations 10221 to 10224) to the continental slope (station 10220), July, 1914

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

"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.

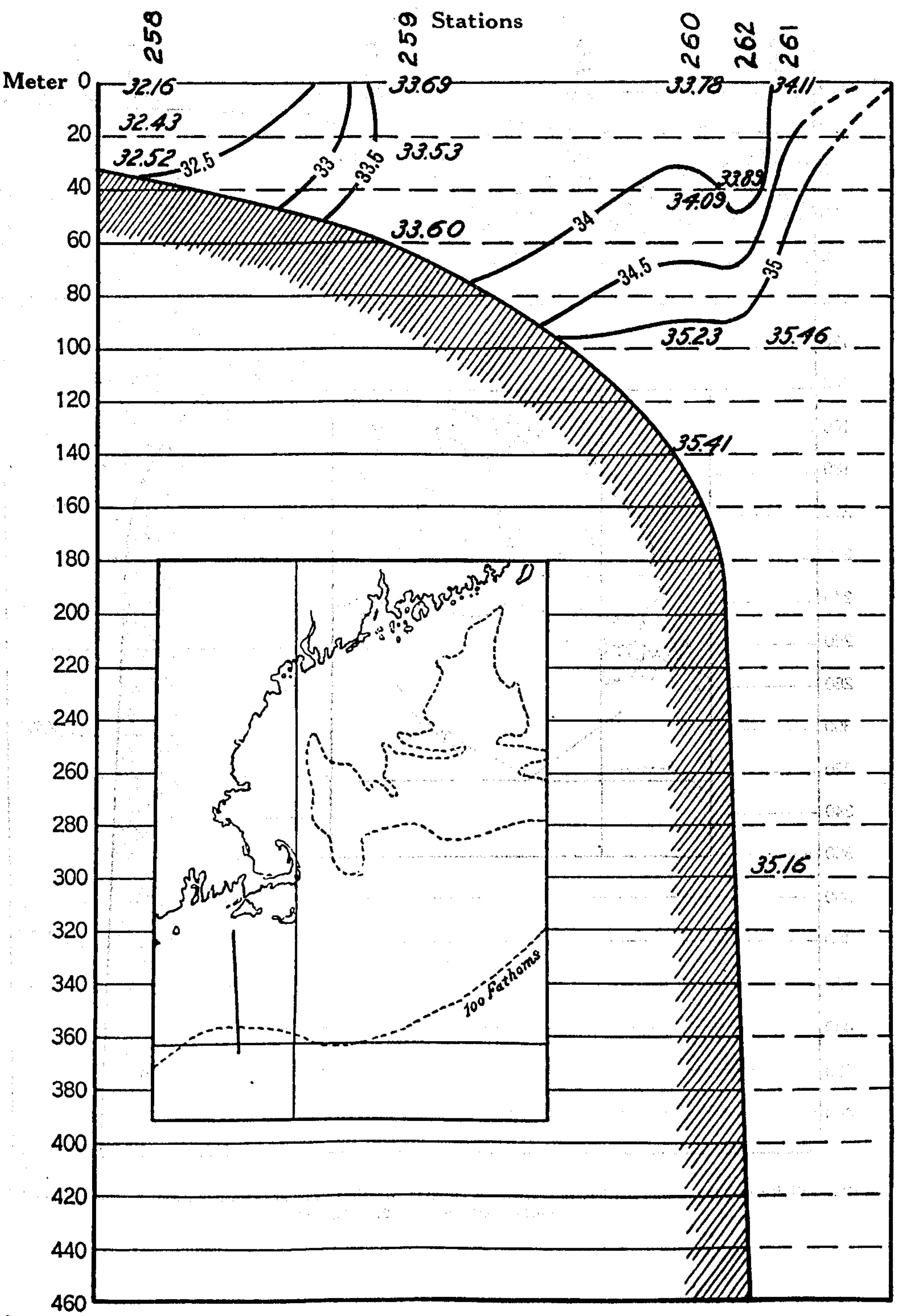

FIG. 158.—Salinity profile running southward from the offing of Marthas Vineyard (station 10258) to the continental slope (station 10261) for August 25 and 26, 1914

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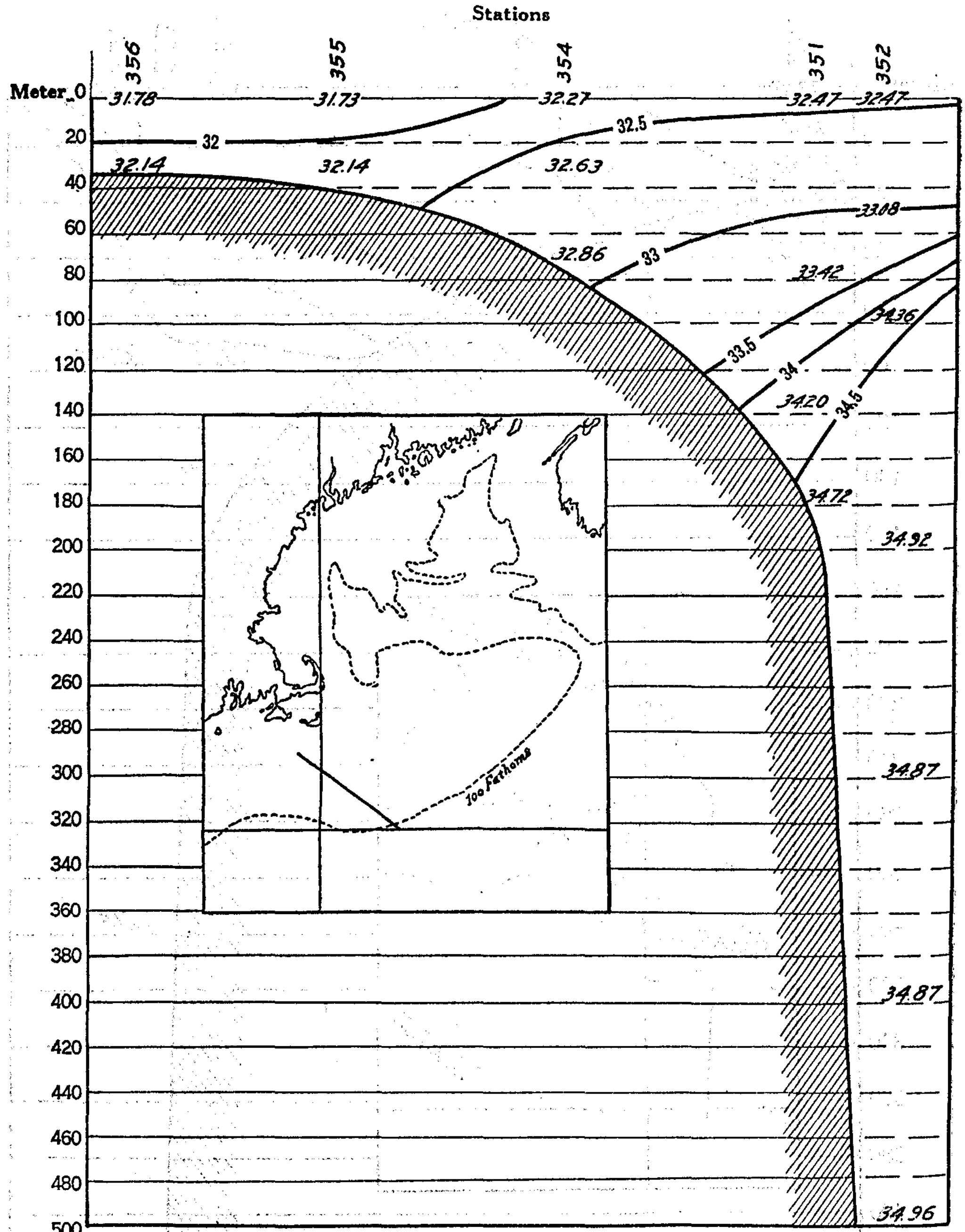

FIG. 159.—Salinity profile running southeasterly from the offing of Marthas Vineyard (station 10356) to the continental slope (station 10352) for July 24 to 26, 1916

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

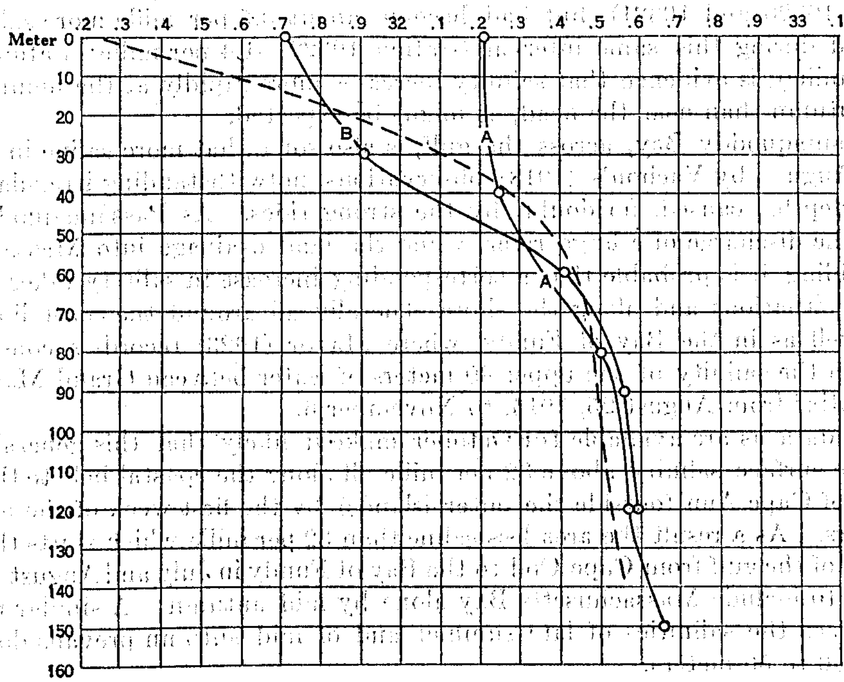

FIG. 160.—Vertical distribution of salinity off Gloucester, August 31, 1915 (station 10306, dotted curve), October 1, 1915 (A, station 10324), and October 31, 1916 (B, station 10399)

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).

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

[4] *Prince* station 3 (Mavor, 1923, p. 375).

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

[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

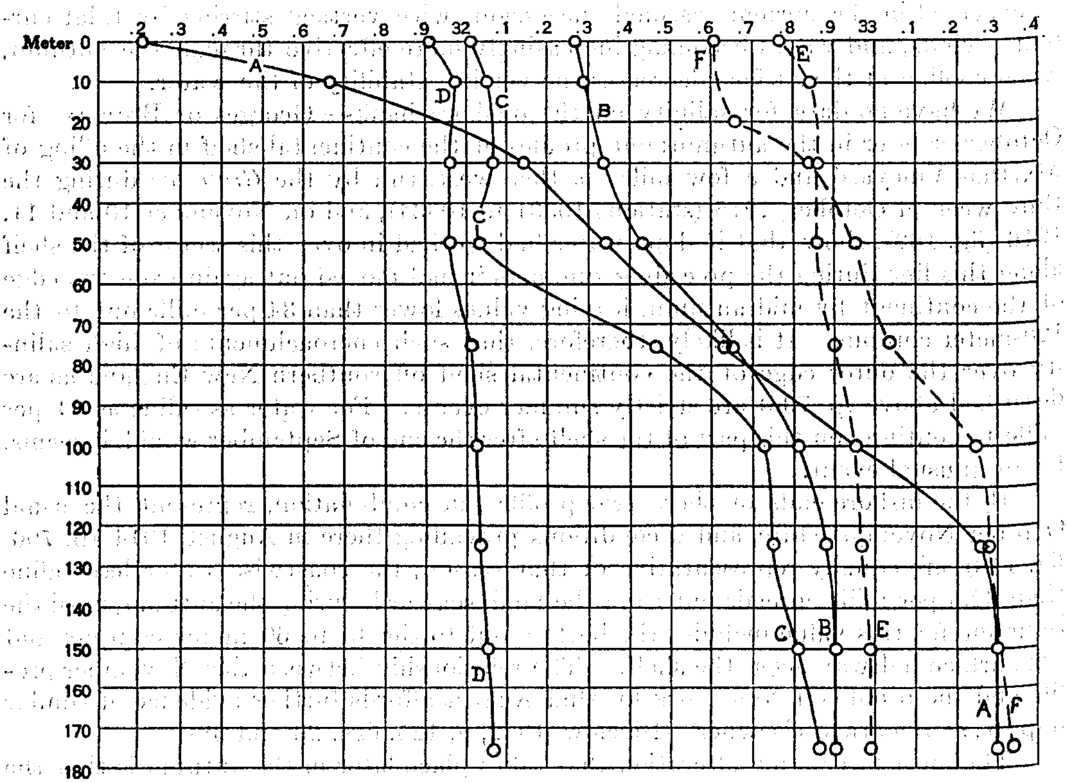

FIG. 161.—Vertical distribution of salinity in the Bay of Fundy between Grand Manan and Nova Scotia, in various months, from Mavor's table (Mavor, 1923, p. 375, *Prince* station 3). A, July 31, 1917; B, October 2, 1917; C, December 5, 1917; D, January 19, 1918; E, December 2, 1916; F, January 3, 1917

raised the salinity of the entire column (now homogeneous, surface to bottom) to about 32.75 per mille by the 23d of that month.

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

[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

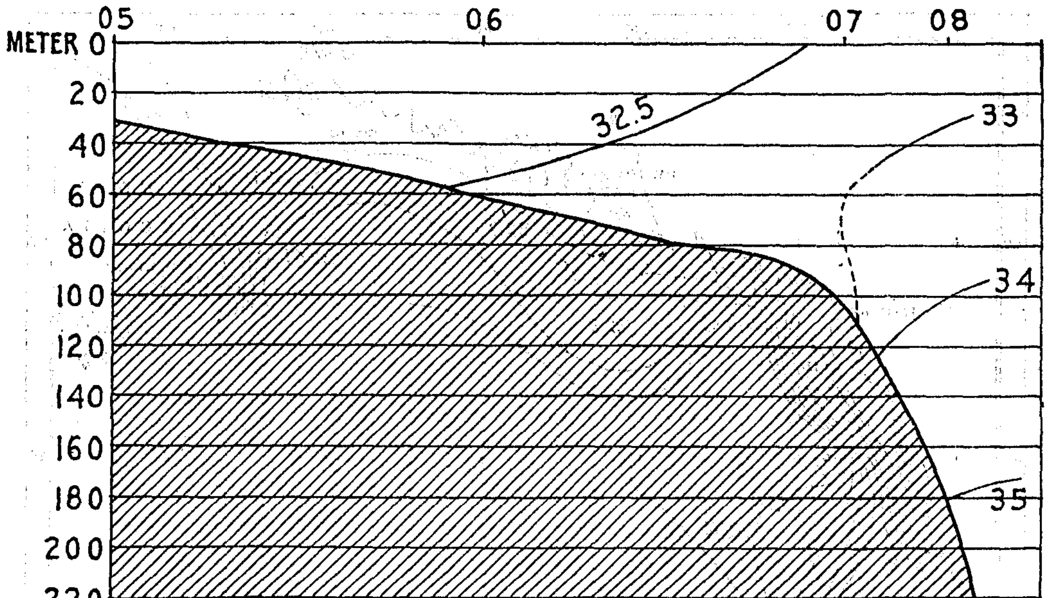

FIG. 162.—Salinity profile crossing the continental shelf off Marthas Vineyard, November 10 and 11, 1916. (From Bigelow, 1922, fig. 38)

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 corroborated 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.

[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

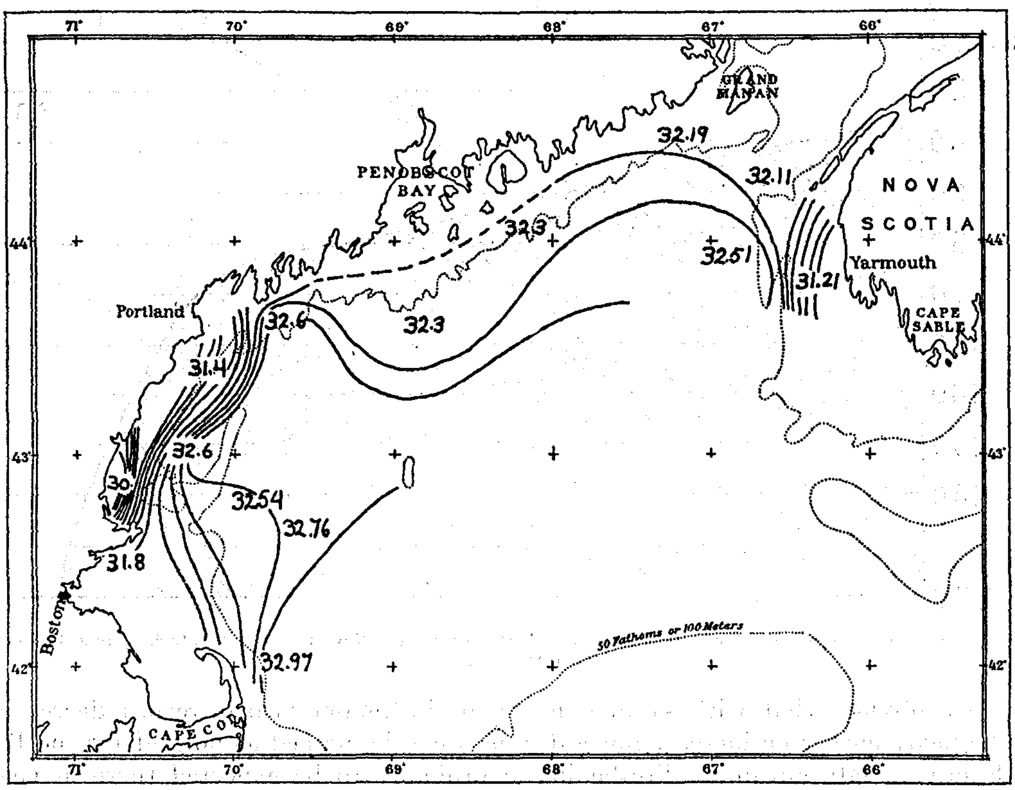

FIG. 163.—Salinity at the surface, December 29 1920, to January 9, 1921. Contours for every 0.2 per mille

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.

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

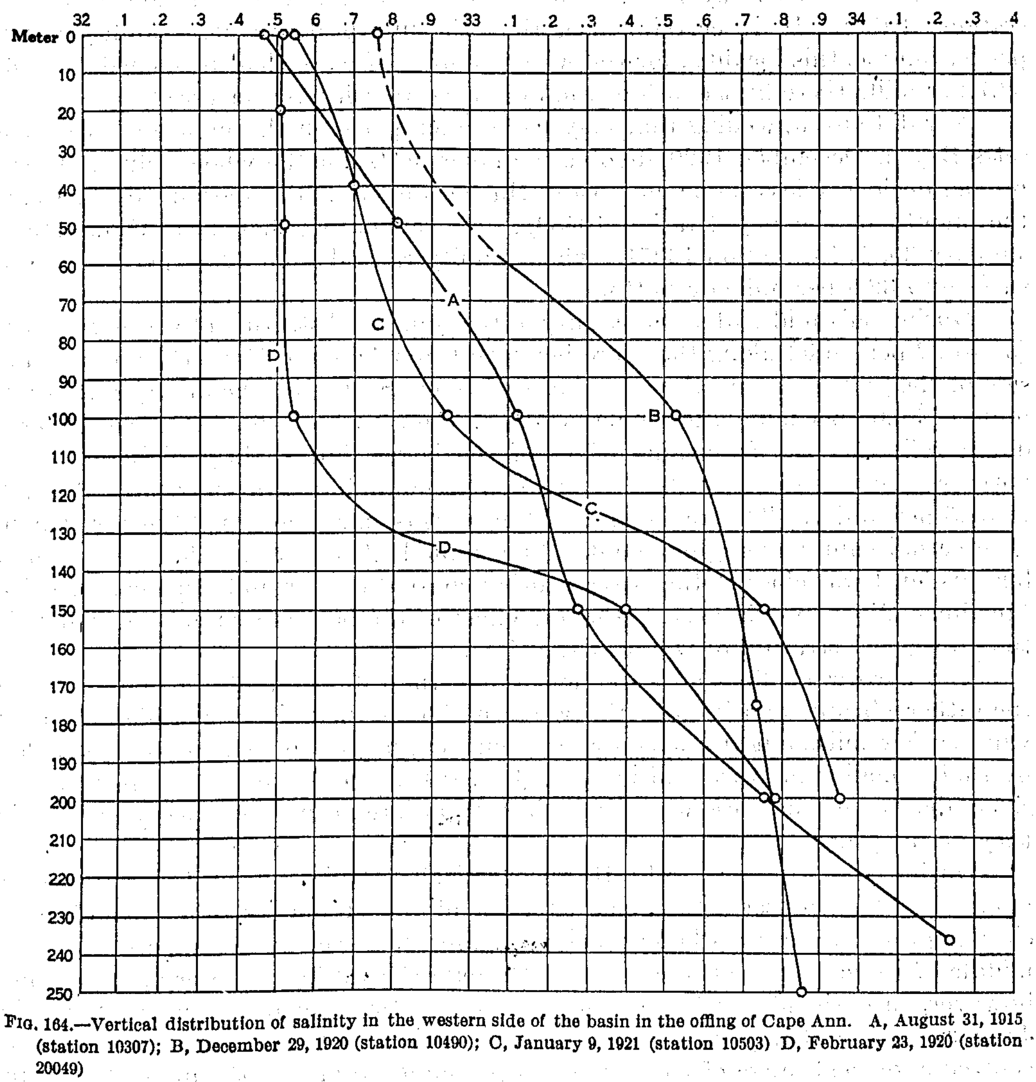

FIG. 164.—Vertical distribution of salinity in the western side of the basin in the offing of Cape Ann. A, August 31, 1915 (station 10307); B, December 29, 1920 (station 10490); C, January 9, 1921 (station 10503) D, February 23, 1920 (station 20049)

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).

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

[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,

[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.

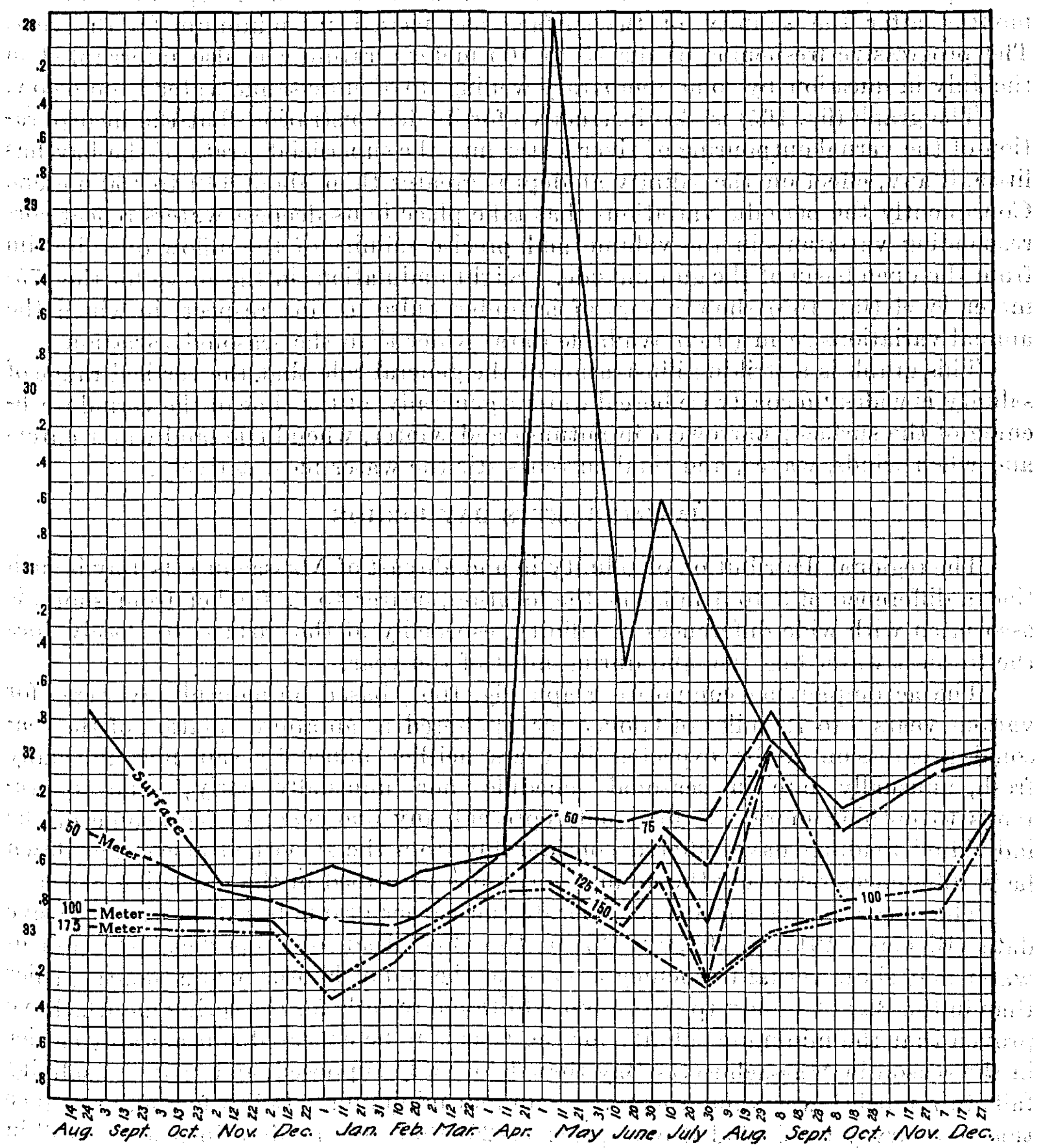

FIG. 165.—Seasonal variations of salinity in the Bay of Fundy, August, 1916, to December, 1917, at the surface, 50 meters, 100 meters, and 175 meters, constructed from Mavor's (1923) tables

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

[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).

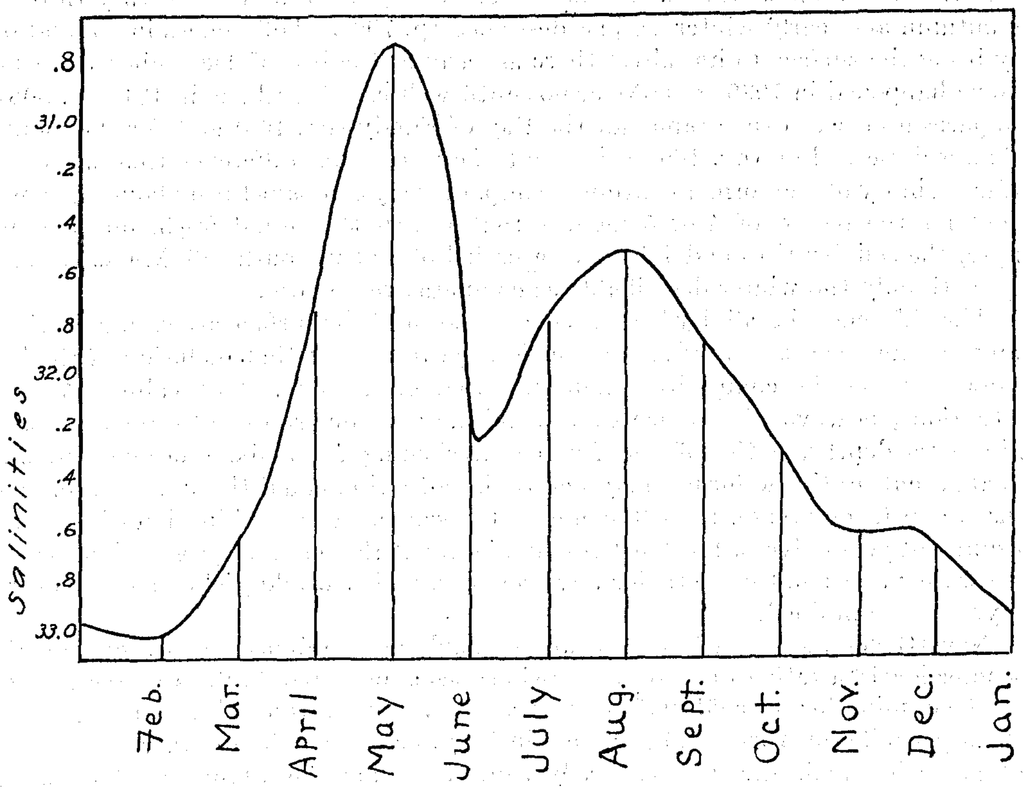

FIG. 166.—Seasonal progression of salinity at the surface at the mouth of Massachusetts Bay, 12 miles off Gloucester, based on monthly averages of the records in the various years. The data for July, 1916, are omitted for the reason given on p. 810

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

[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

[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

[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 hydrogenions. (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.