naturally follow any cold winter or spring (cases in point are 1916 and 1923). If coupled with unusually low salinity, an unusual extension of the Nova Scotian current would be indicated, though this same state might result from a cold winter followed by greater river freshets than usual, a combination not unknown. Abnormally low summer temperature, coupled with high salinity, would result if more slope water than usual was then flowing into the gulf and if it was being incorporated with the overlying water more rapidly than usual.

Temperatures and salinities lower than usual along the outer part of the continental slope abreast the gulf in summer would be conclusive evidence of some unusual expansion of water from the northeast, such as seems actually to have occurred in 1916 (p. 848). If combined with very high salinity, very low temperatures along the edge of the continent would be good evidence of some upwelling from the abyss; and although no upwelling of this sort has come under direct observation off the Gulf of Maine region, or seems likely to occur there, events of this sort would have such a wide-reaching effect on local hydrography that strict watch should be kept for them.

SALINITY[71]

GENERAL SUMMARY

The account of the salinity of the gulf may commence, appropriately, with a brief summary, both because the general reader may find in it information sufficient for his wants and to serve as introductory to the more detailed description.

The Gulf of Maine falls among the less saline of inclosed seas; the salt content of its waters averages very much lower, for instance, than that of the Mediterranean, somewhat lower than that of the North Sea, but higher than that of the Baltic. A close parallel to the Gulf of Maine, in salinity, is to be found in the Skagerak, connecting the Baltic with the North Sea. This relationship was to have been expected because the continental waters along the northwestern margin of the Atlantic are decidedly less saline, as a whole, than on the European side.

Compared with the Gulf of St. Lawrence, the Gulf of Maine shows slightly the higher mean salinity at the surface; but the deep waters of these two gulfs agree very closely in this respect, as they do also in temperature.

Perhaps the most notable feature of the gulf, from the present standpoint, is the abrupt contrast between the decidedly low salinity (averaging only about 32 to 32.5 per mille at the surface and 32.8 to 33 per mille at 100 meters' depth) over and within its offshore rim, and the very much salter (>35.5 per mille) water of the so-called "Gulf Stream," always to be found only a few miles to the seaward of the edge of the continent. This contrast finds its counterpart in the temperature and also in the color of the water.

The Gulf of Maine is also interesting for the wide regional variations in salinity in its inner waters, where, in spite of its small extent, the extremes recorded (about 27 to 35 per mille) cover a range wider than that of the entire Atlantic basin outside

[71] In modern oceanographic parlance the degree of saltness, or "salinity," of the sea water is expressed as the total weight, in grams, of the solids in a state of solution in 1,000 grams of water. This relationship "per thousand," or "per mille," is chosen rather than the more familar term "per cent," merely for convenience to avoid the constant use of small fractional parts.

the 1,000-meter contour. However, even such a range as this is narrow, as compared to temperature, for with the mean salinity of the gulf falling close to 32.5 per mille the extreme variation is not more than 20 per cent. Consequently, I must caution the reader that while emphasis is laid on these variations in the following pages, they are actually so small, from season to season and from place to place, that their measurement requires careful chemical or physical tests. They could not be detected by any human sense. To use a homely example, no one, I fancy, could distinguish the saltest water of the gulf from the freshest by its taste, but no one could fail to tell the temperature of winter from that of summer if he dipped his hand in the water or by feeling the spray on his face.

The gulf is invariably saltest in the eastern side of its trough and in the Eastern Channel, which connects the latter with the open ocean. It is freshest in the coastwise belt along its northern and western shores and along the western shoreline of Nova Scotia, as appears repeatedly on the charts of salinity for various levels and seasons.

The fact that the water over Georges Bank (the shoal southern rim of the gulf) is not salter than the basin to the north of it deserves emphasis because its proximity to the oceanic waters of the "Gulf Stream" might lead us to expect high salinities there.

A wide seasonal variation in the salinity of the surface is characteristic of coastwise waters in boreal latitudes, the water freshening at the season of the spring freshets and then gradually salting again as this inrush of river water is incorporated by the mixings and churnings caused by the tides, winds, and waves.

The Gulf of Maine is no exception to this rule. The widest seasonal variations so far actually recorded there at any given station are from about 28 per mille in April to about 32.7 per mille in winter in the Bay of Fundy (fig. 165), and from about 28.3 per mille in May to about 32.3 per mille in early March in the opposite side of the gulf, a few miles off the mouth of the Merrimac River (p. 813). Such changes, however, are confined to the superficial stratum of water not over 40 meters thick. The bottom waters of the gulf deeper than 100 meters see very little alteration in salinity from season to season. The salinity has also proved unexpectedly constant from year to year in all parts of the gulf at any given season.

The Gulf of Maine is characterized by a considerable vertical range in salinity over all but its most tide-stirred portions, contrasting strongly in this respect with the North Sea, across the Atlantic, where the salinity as a whole is more nearly uniform from the surface downward. The vertical range is widest in spring and summer, when the surface as a whole is freshest, narrowest toward the end of the winter; greatest, too, where the stirring effects of the tides are least, as in the western side of the gulf off Massachussetts Bay, and least where tidal currents keep the water more thoroughly churned, as in the Bay of Fundy in one side of the gulf or on Nantucket Shoals in the other.

In summer, and in the coastwise zone, the increase in salinity with depth averages most rapid from the surface down to a depth of about 50 to 75 meters; but there are many exceptions, and in the deep basin of the gulf the salinity gradient may be nearly uniform, surface to bottom, or the rise in salinity may be found most rapid as the bottom is approached.

DETAILED ACCOUNT OF SALINITY

The detailed account of the salinity of the gulf may well commence with its state at the end of the winter and during the first days of spring, both because this is the season when variations in salinity, both regional and vertical, are least, and because this choice of a point of beginning will parallel the description of the temperature of the gulf (p. 522).

FEBRUARY AND MARCH

At the end of February and during the first week of March the salinity of most parts of the gulf is at or near its maximum for the year, except close to the mouths of the larger rivers. It is also most nearly uniform then regionally, having had a range of only 1.3 per mille from station to station at the surface in March, 1920. In the offshore parts of the gulf the salinity is then also close to uniform vertically, from the surface down to a depth of 40 to 50 meters, but increases at greater depths down to the bottom of the trough, as is the general rule in all parts of the Gulf of Maine at all seasons.

SURFACE

During the last week of February and the month of March of 1920 (which we must, perforce, take as representative, being the only year when we have made a general survey of the gulf at this season) the surface water was freshest (31.3 to 32 per mille) along a narrow band fringing the coast between Portland and the eastern boundary of Maine (fig. 91); and it is probable that equally low salinities prevailed in the more inclosed bays and in the mouths of harbors all around the coast line of the gulf at that time. The curves for successive values show that this band of water, less saline than 32 per mille, was probably not wider than 20 miles (measured from the outermost islands or headlands) on any line normal to the coast, with rather an abrupt transition to salinities higher than 32 per mille a few miles to the seaward of the 100-meter contour. In outlining the distribution of salinity farther out from the land, the curve for 32.5 per mille is the most instructive, its undulating course marking an artificial boundary between the fresher and salter waters. Water fresher than this overspreads the entire northwestern and western portions of the gulf at this season and its eastern side as well, spreading offshore to include the whole western half of Georges Bank, a considerable area off Penobscot Bay, and the whole breadth of the continental shelf (including Browns Bank) to the southward of Cape Sable.[79]

The salinity of the surface water in the offing of the cape is especially interesting at this season as evidence of the extent to which the icy waters of the Nova Scotian current (characterized equally by low salinity) have begun to flood westward past the cape into the Gulf of Maine. In 1920 the situation of the isohaline for 32.2 per mille on this March chart clearly shows that the freshest (also the coldest) core of this drift lay well out from the shore off southern Nova Scotia, directed toward Browns Bank, and that it had not yet passed the longitude of Cape Sable in appreciable volume. The low salinity of the waters that then skirted the western

[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).

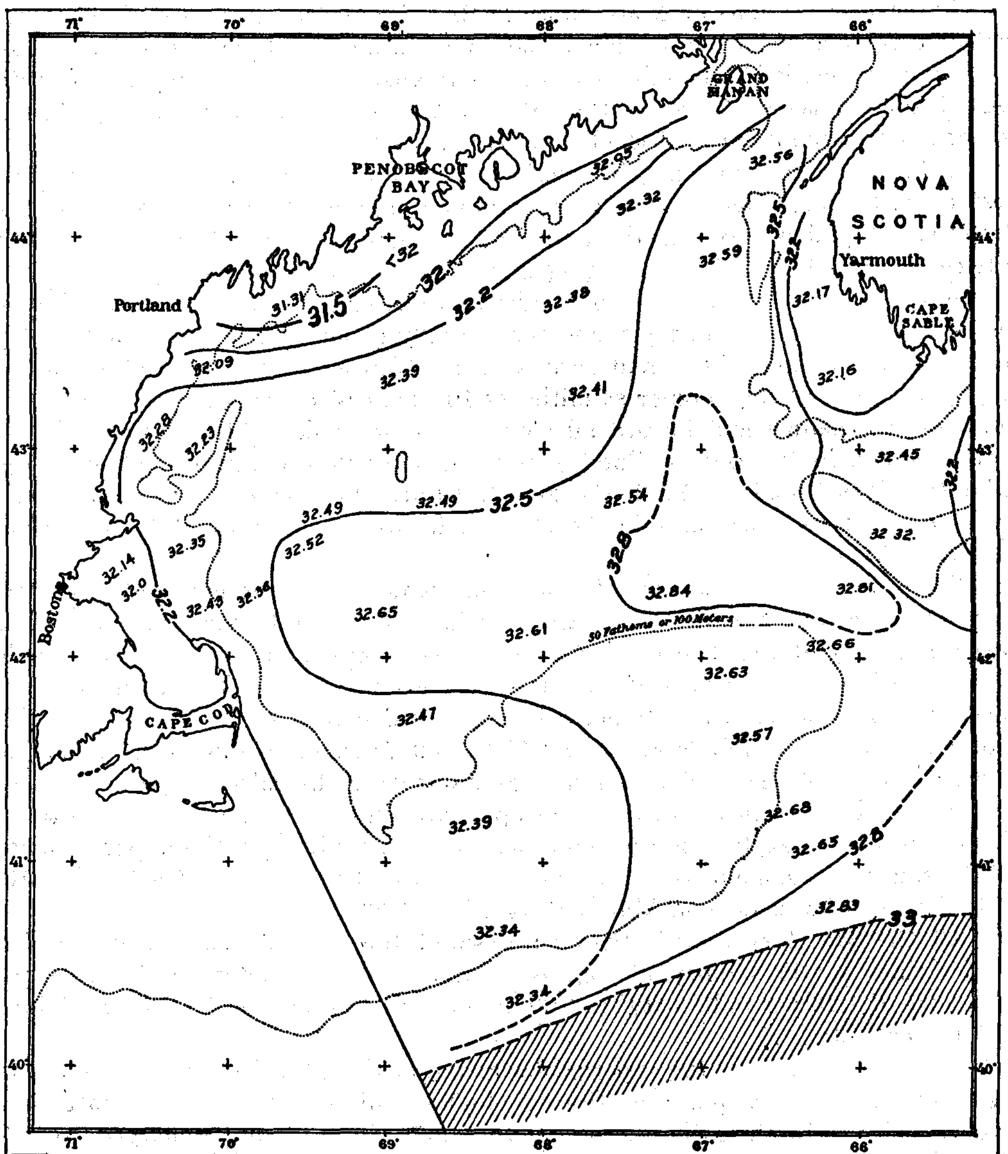

FIG. 91.—Salinity at the surface, February 22 to March 24, 1920. The isohaline for 33 per mille is assumed

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.

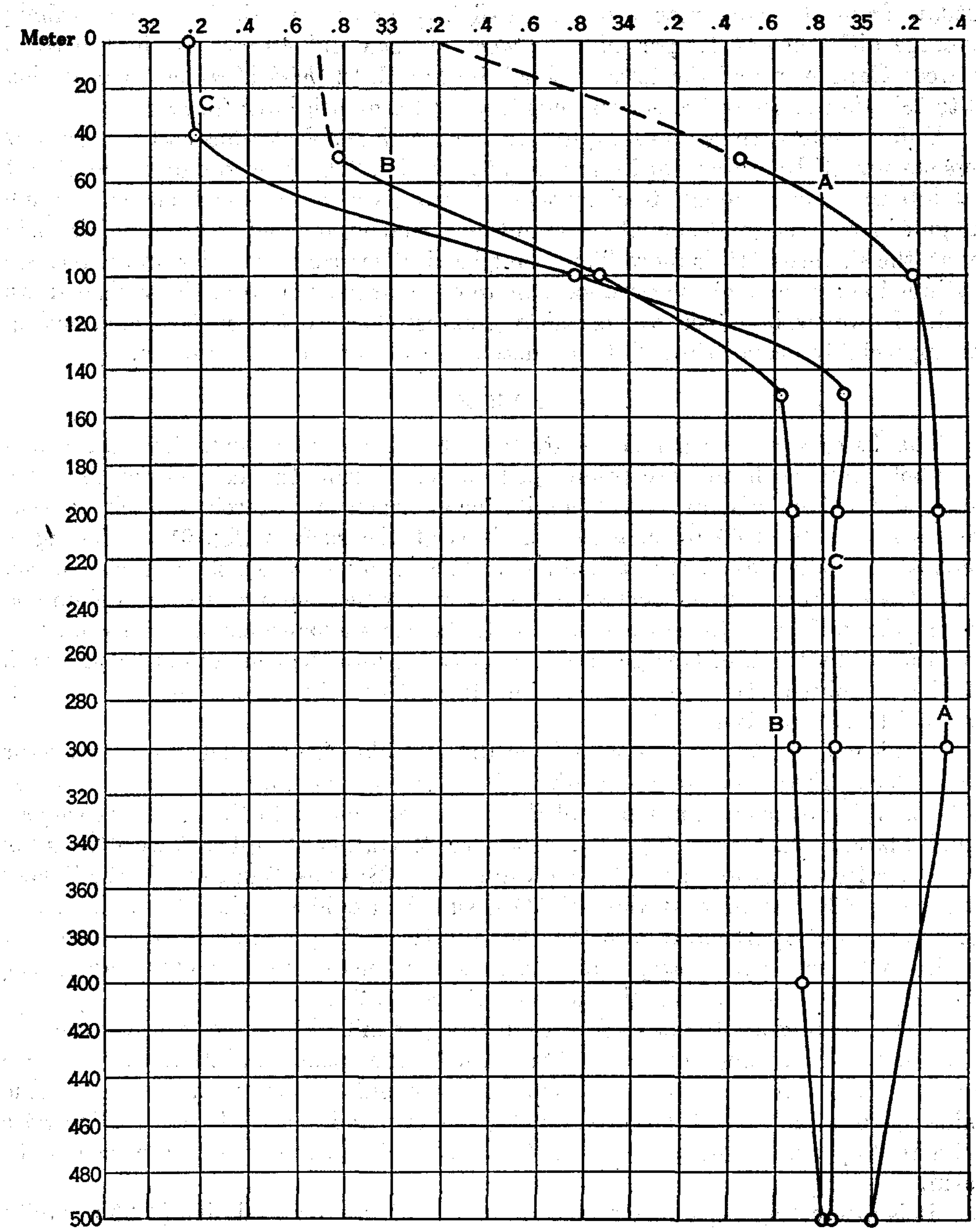

FIG. 92.—Vertical distribution of salinity on the continental slope abreast the gulf and off Shelburne, Nova Scotia, February to March, 1920, A, southwest of Georges Bank, March 22 (station 20044); B, off the southeast slope of Georges Bank, March (station 20069); and C, off Shelburne, Nova Scotia, March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

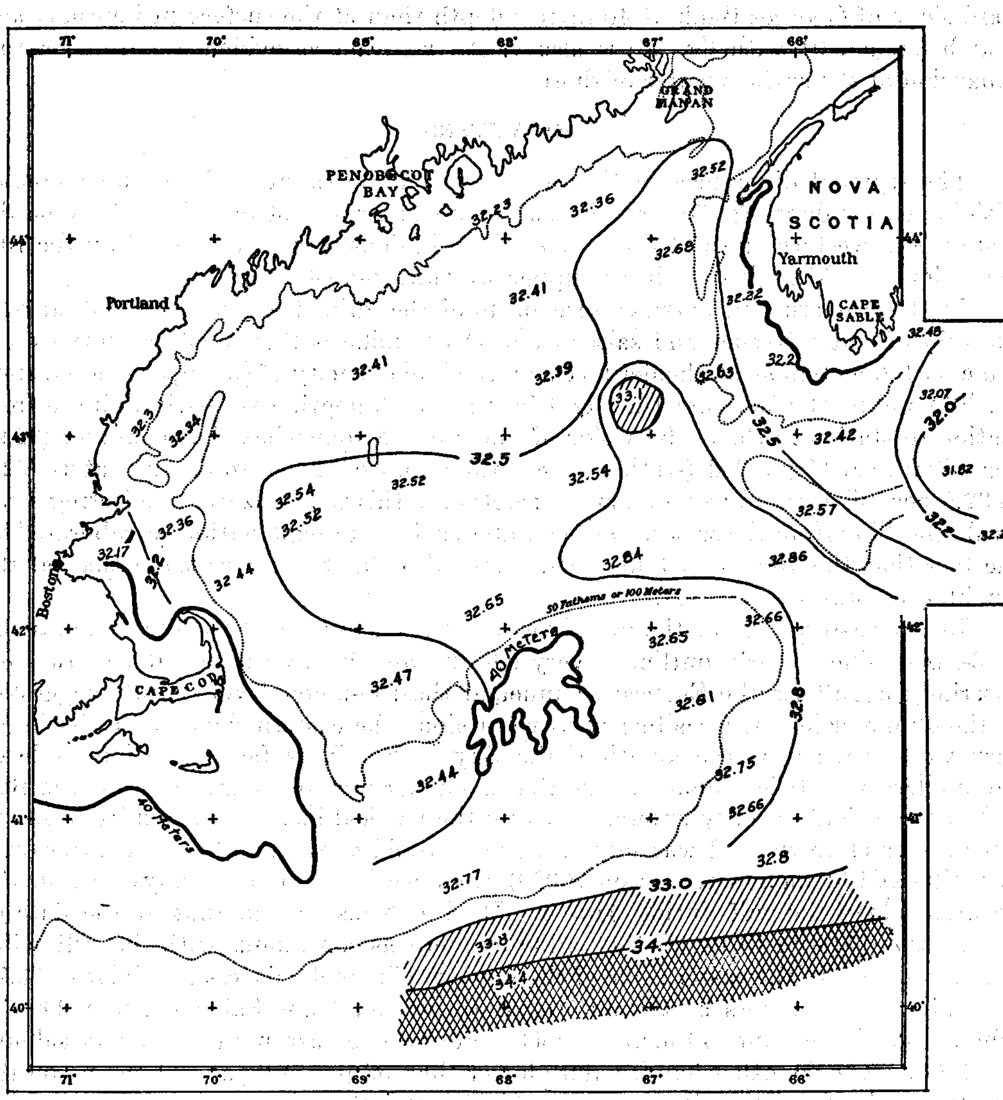

FIG. 93.—Salinity at a depth of 40 meters, February 22 to March 24, 1920

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.

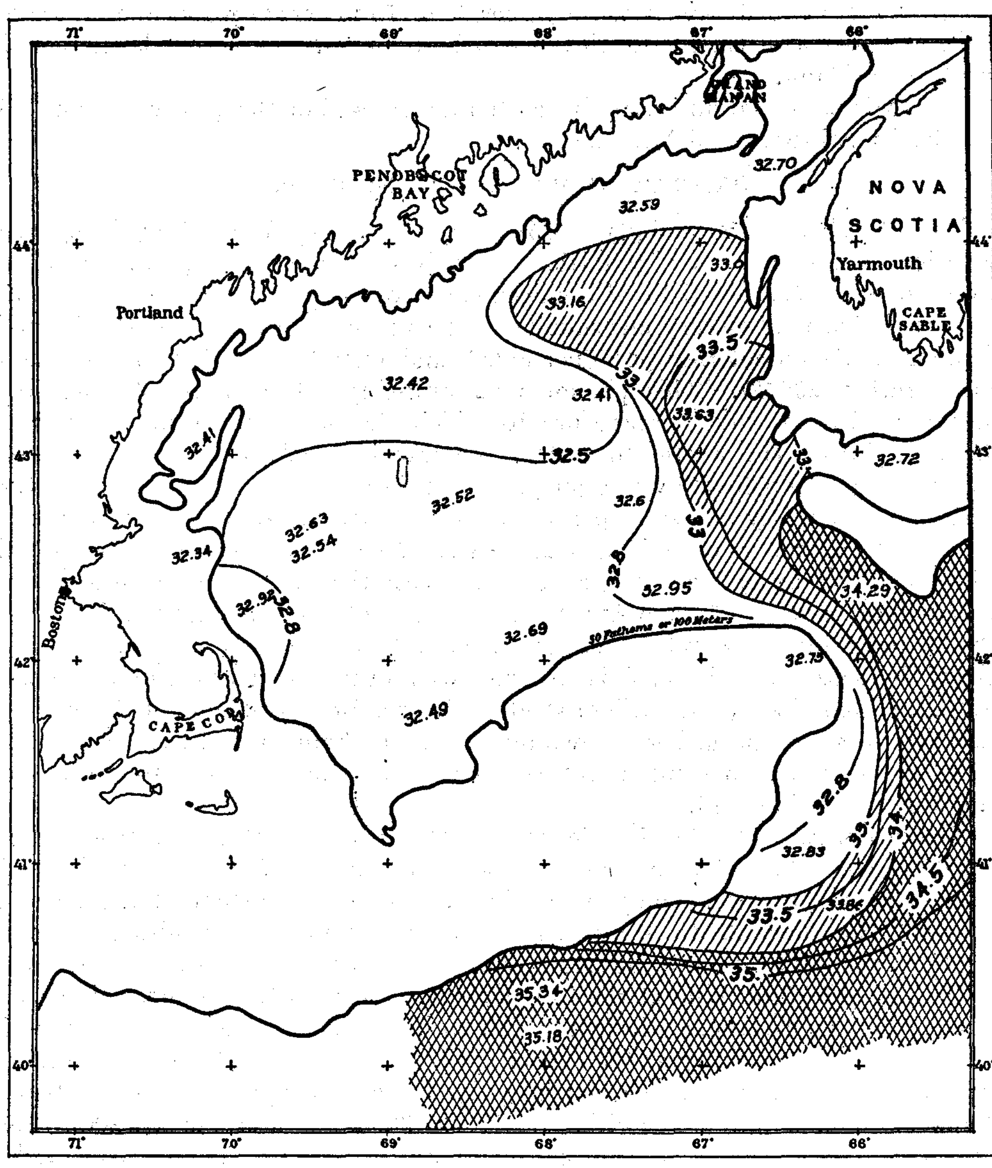

FIG. 94.—Salinity at a depth of 100 meters, February 22 to March 24, 1920

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.

[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.

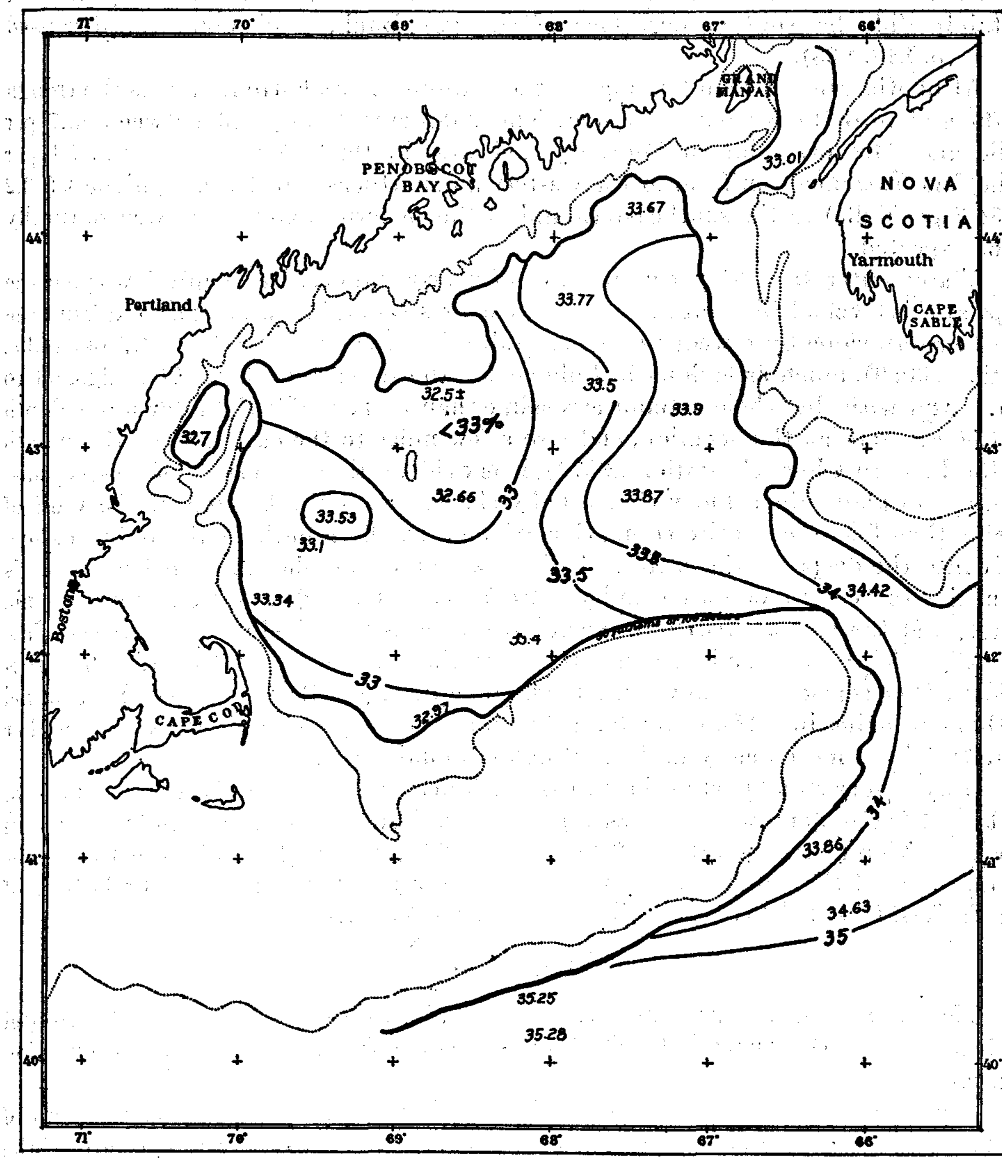

FIG. 95.—Salinity at a depth of 150 meters, February 22 to March 24, 1920

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)

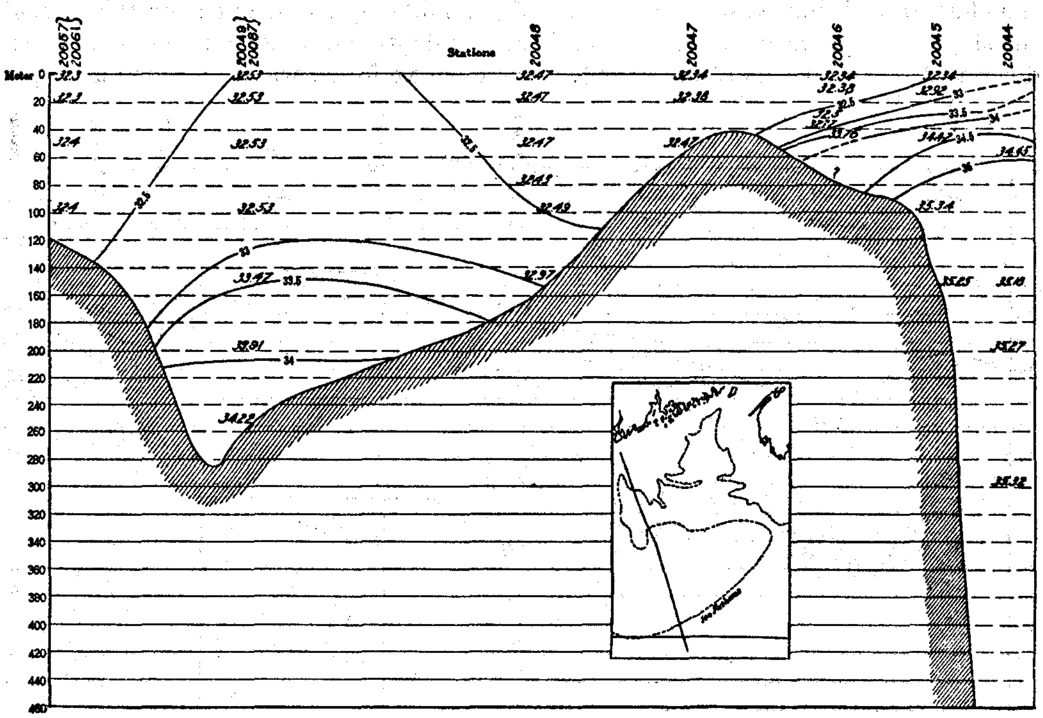

FIG. 96.—Salinity profile running southward from the offing of Casco Bay, across Georges Bank, to the continental slope, February 22 to March 5, 1920

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

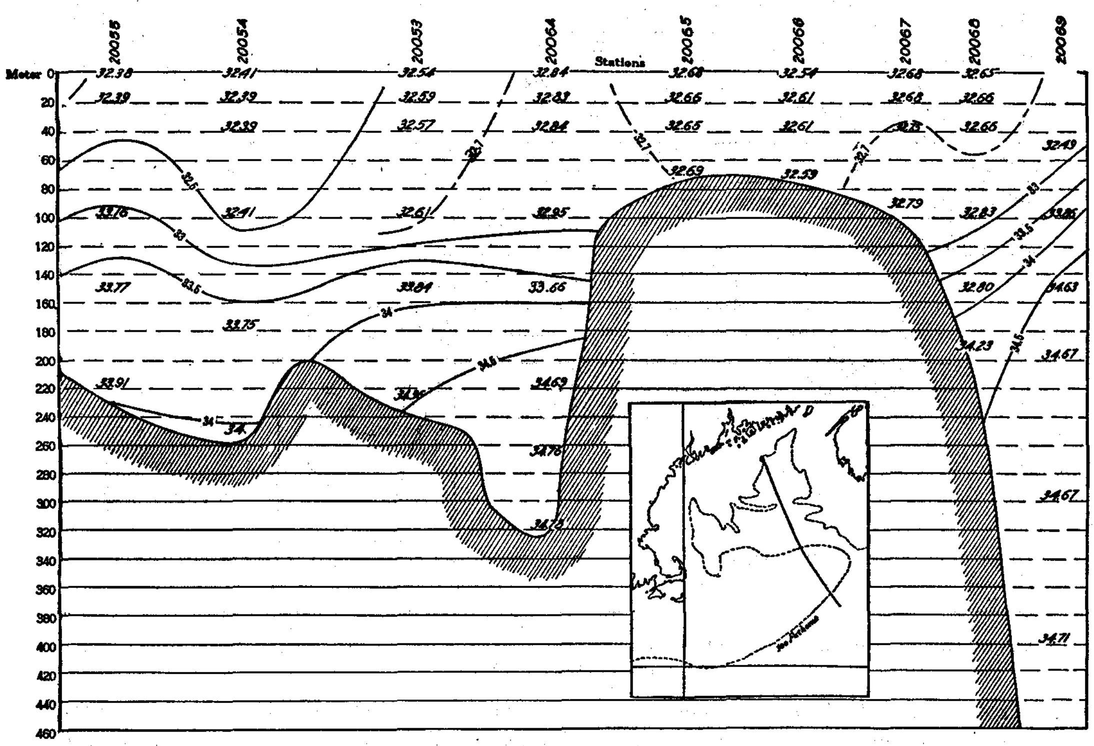

FIG. 97.—Salinity profile running from the vicinity of Mount Desert Island, southward across the gulf and across Georges Bank to the continental slope, March 3 to 12, 1920

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

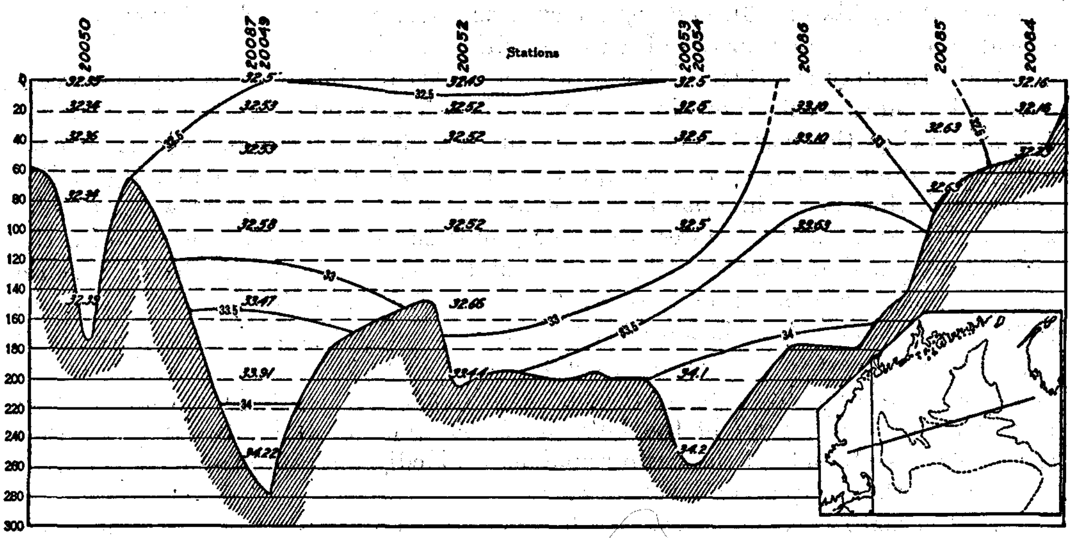

FIG. 98.—Salinity profile running eastward from Massachusetts Bay, across the gulf toward Cape Sable, March 1 to 23, 1920

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

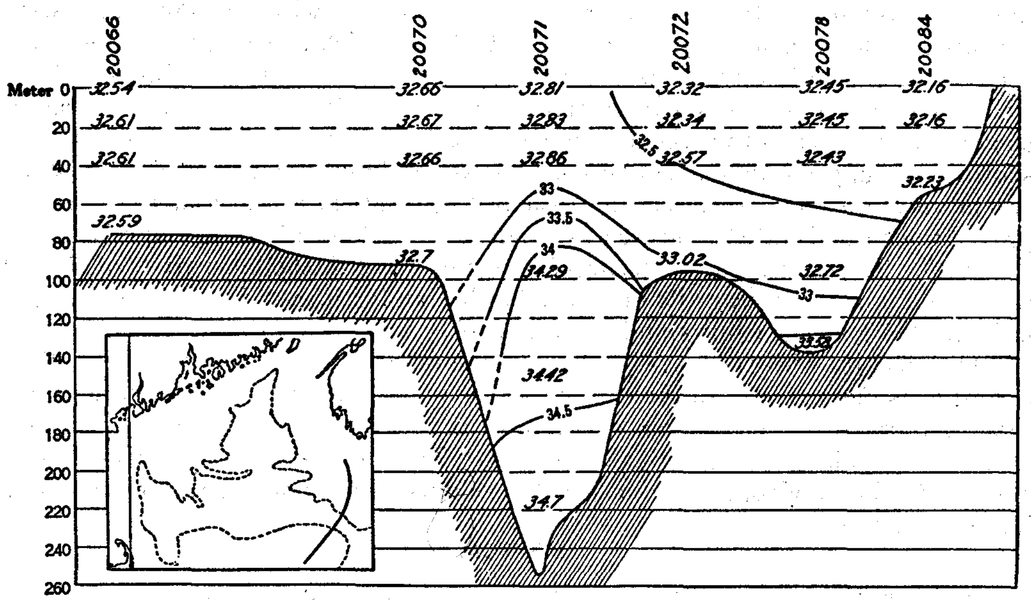

FIG. 99.—Salinity profile running from the eastern part of Georges Bank across the Eastern Channel, Browns Bank, and the Northern Channel, to the offing of Cape Sable, March 11 to 23, 1920

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 not yet freshened the upper 50 meters of water as far west as Browns Bank to a value (32.5 per mille) appreciably lower than had probably prevailed there a week or two earlier in the month. This locates the first extension of this comparatively fresh current as directed toward the southeast and not around Cape Sable into the inner part of the gulf, though there is evidence that some of this Nova Scotian water drifts right across the Eastern Channel later in the season and far westward along the outer side of Georges Bank (p. 848).

LIMITS OF WATER MORE SALINE THAN 34 PER MILLE

Salinities higher than 34 per mille, whenever encountered in the deep trough of the gulf, are unmistakable evidence that indraft is either taking place from the region off the mouth of the Eastern Channel at the time, or has taken place so recently that the saline water from this source has not yet been appreciably diluted during the sojourn in the basin of the gulf by mixture with the less saline water beneath which it spreads. A chart of the depth to which it would have been necessary to descend to find water as salt at 34 per mille in the gulf in March, 1920, as well as its horizontal limits, irrespective of depth (fig. 100), is therefore instructive as graphic evidence of the recent activity of this movement. The gradient there shown, with upper boundary of 34 per mille water lying 100 meters deeper at the two heads of the two branches of the Y-shaped trough than in the Eastern Channel, is proved the normal state by close correspondence with April (fig. 118) and midsummer (fig. 152). It represents the consumption of this water in the inner parts of the gulf as vertical mixing destroys its identity, and has an important bearing on the circulation of the gulf from this standpoint (p. 849).

Comparison with the corresponding isothermobath (fig. 20) shows that salinity corresponds more closely to the contour of the bottom than to temperature at this season, there being no reason to suppose that water as saline as 34 per mille encroaches at all on Georges Bank in spring. The north–south ridge, which culminates in Cashes Ledge, also influences the salinity of the bottom water more than its temperature.

BOTTOM

The salinity on bottom is interesting chiefly for the biologist who is concerned with the physical conditions to which the bottom fauna is subject. In any small subdivision of the Gulf of Maine this is governed directly by the depth, with the water saltest where deepest; but when the survey is expanded to cover the area as a whole, account must also be taken of the regional differences just described, especially of higher salinities in the eastern side than in the western, and of freshenings of the coastal zone, whether by river freshets or by the Nova Scotian current. Early in the spring, before these last influences have altered the water appreciably from its winter state, the differences in salinity between the two sides of the gulf are widest in the mid depths. Consequently we find the regional variation in bottom salinity is then widest somewhat more than midway down the slopes of the basin, near the 100-meter contour.

In March, 1920, the bottom water of this belt varied in salinity from about 32.3 per mille to 32.5 per mille, along the western and northern margins of the gulf, to about 33.5 per mille on its eastern slope, with a corresponding west–east gradation at greater depths from about 34 per mille at the bottom of the western and northeastern parts of the trough to about 34.8 per mille in the southeastern part, irrespective of slight differences in depth.

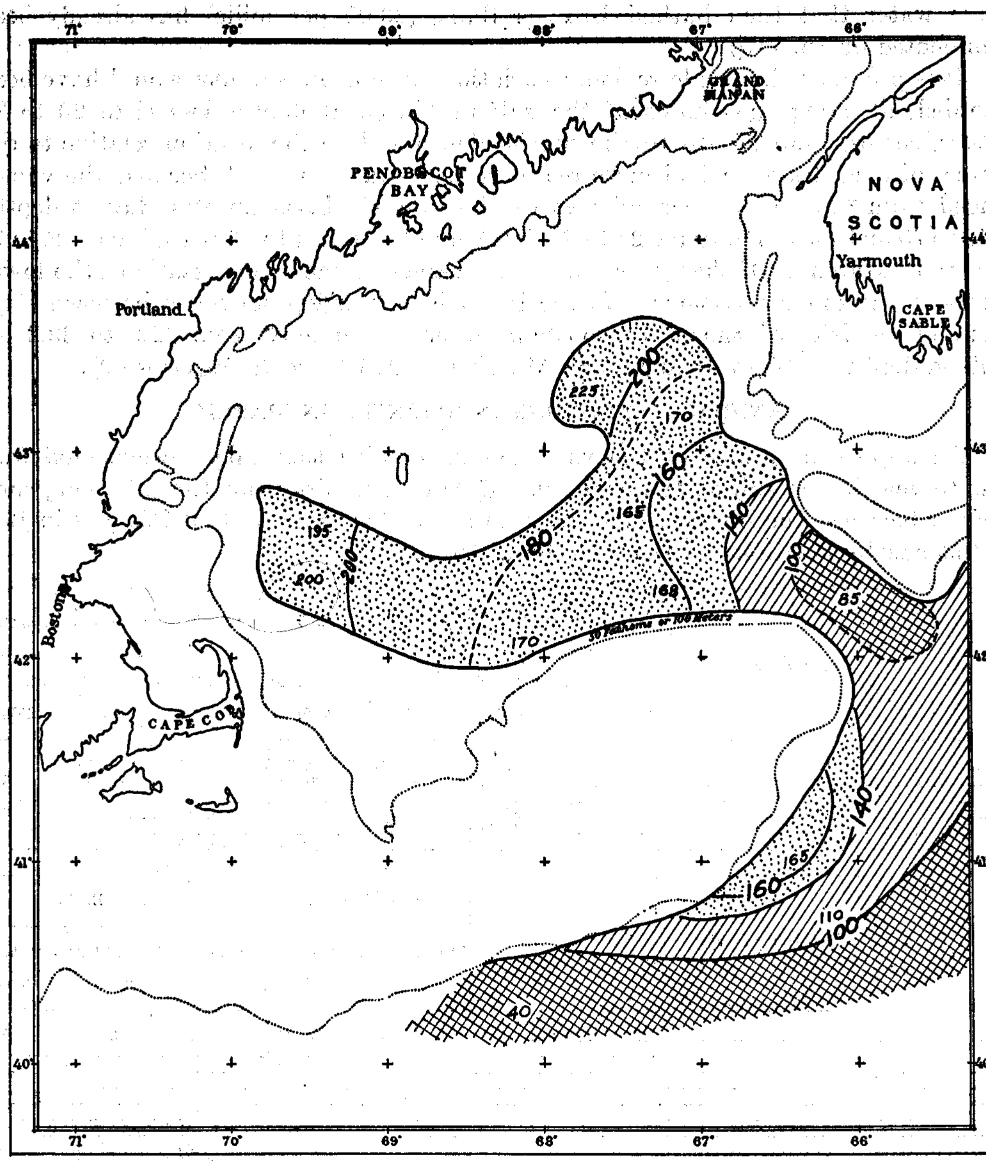

FIG. 100.—Depth below the surface of the isohalobath of 34 per mille, February to March, 1920

Thanks to the vertical homogeneity of the water at this season at depths less than 100 meters, the bottom salinity of the coastal zone was then very uniform from station to station (about 32.3 to 32.6 per mille at most of the stations) in depths of 40 to 100 meters. The bottom water proved equally uniform on Georges Bank, where the extremes recorded (32.6 and 32.8 per mille) were only 0.2 per mille apart in spite of the very considerable area covered by the stations and the variation in depth from 50 to 90 meters.

The contrast between this low bottom salinity on Georges Bank and the more saline water that then bathed Browns Bank (33.02 per mille) has already been commented on (p. 719).

It is probable that wide regional variations in bottom salinity would have been recorded all along the shores of the gulf in March at depths less than 20 to 30 meters, corresponding both to the precise depth and to the location relative to the sources of land drainage, had more readings been taken so shoal, because the values ranged from 32.3 to 33.1 per mille at the bottom of Massachusetts Bay at depths of 12 to 70 meters on February 24 to 28, 1925, and from 32.4 to 33 per mille at 25 to 76 meters on March 10 of that year, the higher values at the deeper stations, the lower values at the shoaler stations. In the Ipswich Bay region, however, between Cape Ann and the Isles of Shoals, the bottom water varied only from 32.9 to 33.2 per mille in depths of 30 to 64 meters on March 12, 1925 (*Fish Hawk* cruise 9).

ANNUAL VARIATIONS IN SALINITY IN MARCH

An approximate idea of the variation in salinity that may be expected from year to year in the gulf at the beginning of March results from the following comparison between the observations taken in its western side by the *Albatross* in 1920 and at nearby locations by the *Halcyon* in 1921:

Depth, meters	Mouth of Massachusetts Bay		Near Isles of Shoals		Off Cape Elizabeth	
	Mar. 1, 1920 20050	Mar. 5, 1921 10511	Mar. 5, 1920 20061	Mar. 5, 1921 10509	Mar. 4, 1920 20059	Mar. 4, 1921 10507
0	32.35	32.64	32.2	32.85	32.09	32.35
40	32.36	32.70	32.34	32.79	[1]32.20	32.47
90					32.32	
100	32.34	32.76	32.41	32.86		32.47
150	32.39	32.70				
175			32.91	32.99		

Depth, meters	Off Seguin Island		Western Basin		
	Mar. 4, 1920 20058	Mar. 4, 1921 10508	Feb. 23, 1920 20049	Mar. 24, 1920 20087	Mar. 5, 1921 10510
0	31.31	32.32	32.52	32.49	32.49
15	32.00	32.30			
30		32.30			
40				32.54	32.47
45	32.34				
50			32.52		
60		32.41			
100			32.54	32.63	32.65
150			33.40	33.53	33.12
200			33.78	34.05	
225					33.08
250				34.22	33.99

[1] Approximately.

These tables show salinities averaging about 0.4 per mille higher in 1921 than in 1920, at depths less than 150 meters along the coastal zone from the mouth of Massachusetts Bay to the neighborhood of Cape Elizabeth; but the readings for the two years were substantially alike off Seguin Island. This also applies to the western basin above the 100-meter level; but 1920 was the salter year there at greater depths, with an annual spread of 0.5 to 1 per mille at 150 to 200 meters.

With so little difference in salinity between the two years it is safe to assume neither was unusually fresh or unusually salt, but that the two together may be assumed to represent a typical Gulf of Maine March.[85]

Judging from one station at the mouth of Massachusetts Bay, with readings of 32.85 per mille at the surface, 32.96 per mille at 25 fathoms, and 33.04 per mille at 45 fathoms (station 10054), the March salinity was about the same in 1913 as in 1921. Again, the salinity of the upper 100 meters of the Fundy Deep was almost precisely the same on March 22, 1920 (station 20079), as on April 9, 1917 (Mavor, 1923); the 150-meter level the same as on February 28 of that year, though 1920 seems to have been slightly the salter at depths greater than 150 meters.

Thus, the March salinity of the gulf showed but little annual variation in the years 1913, 1917, 1920, and 1921, and it is probable that annual differences are smallest at this season. Even in March, however, much wider differences than those just stated are to be expected between springs of heavy or light rainfall and snowfall, or between years when the freshets occur unusually early or unusually late. Fluctuations in the bottom current flowing into the gulf will also be mirrored by salinity.

Hydrometer observations taken in Massachusetts Bay and to the northward of Cape Ann from the *Fish Hawk* on March 10 to 12, 1925, give a hint of this in bottom readings considerably higher than we had previously obtained there at that season—an average of about 33 per mille at 40 to 60 meters depth contrasting with 32.2 to 32.5 per mille for 1920 and 1921. The superficial stratum was likewise slightly more saline in Massachusetts Bay in March, 1925 (32.4 to 32.9 per mille), than in either of the earlier years of record.

VERNAL FRESHENING

The great rush of fresh water that annually pours into the gulf from the land, when the snow melts and brings the rivers into freshet, causes a very decided lowering of salinity contemporaneous with the first signs of vernal warming. The effect of this, first apparent along the western and northern shores of the gulf, had considerably lowered the surface salinity of the superficial stratum off the Kennebec River by March 4 in 1920, a late year (p. 704). The upper 30 to 40 meters of the coast sector between northern Cape Cod and the neighborhood of Mount Desert Island proved decidedly less saline by the 9th to 18th of that April (fig. 101), also, than it had been a month earlier (fig. 91).

Localization of the lowest salinities (in this case <30 per mille) between Cape Elizabeth to the west and Penobscot Bay to the east, up to this date, is evidence that the Kennebec and the Penobscot combined had continued to affect the salinity more than the Saco and the Merrimac did until mid-April in that particular year; but whether a seasonal relationship of this sort is normal, or whether the freshening effect of these two groups of rivers is more nearly simultaneous in most years than

[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.

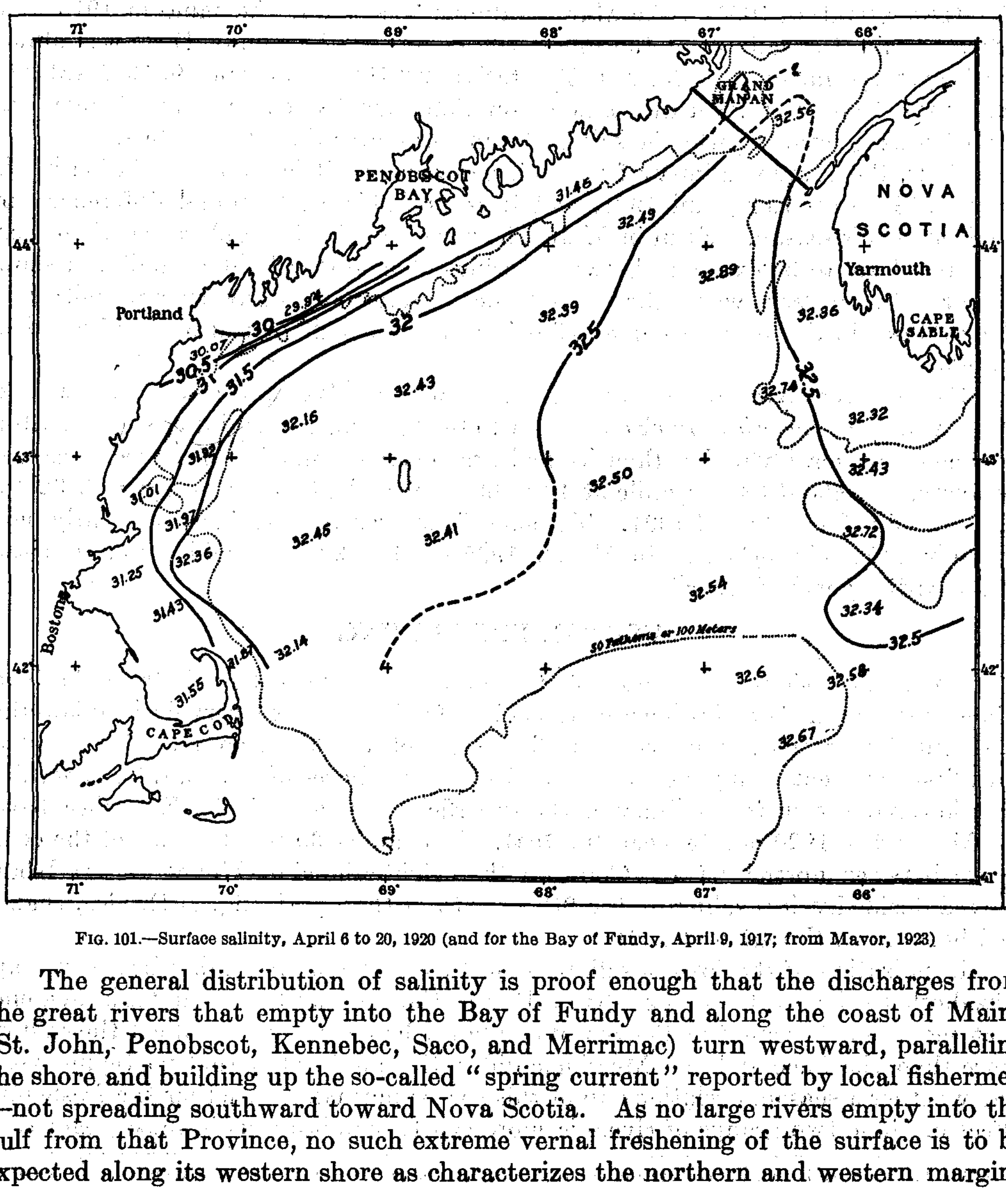

FIG. 101.—Surface salinity, April 6 to 20, 1920 (and for the Bay of Fundy, April 9, 1917; from Mavor, 1923)

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.

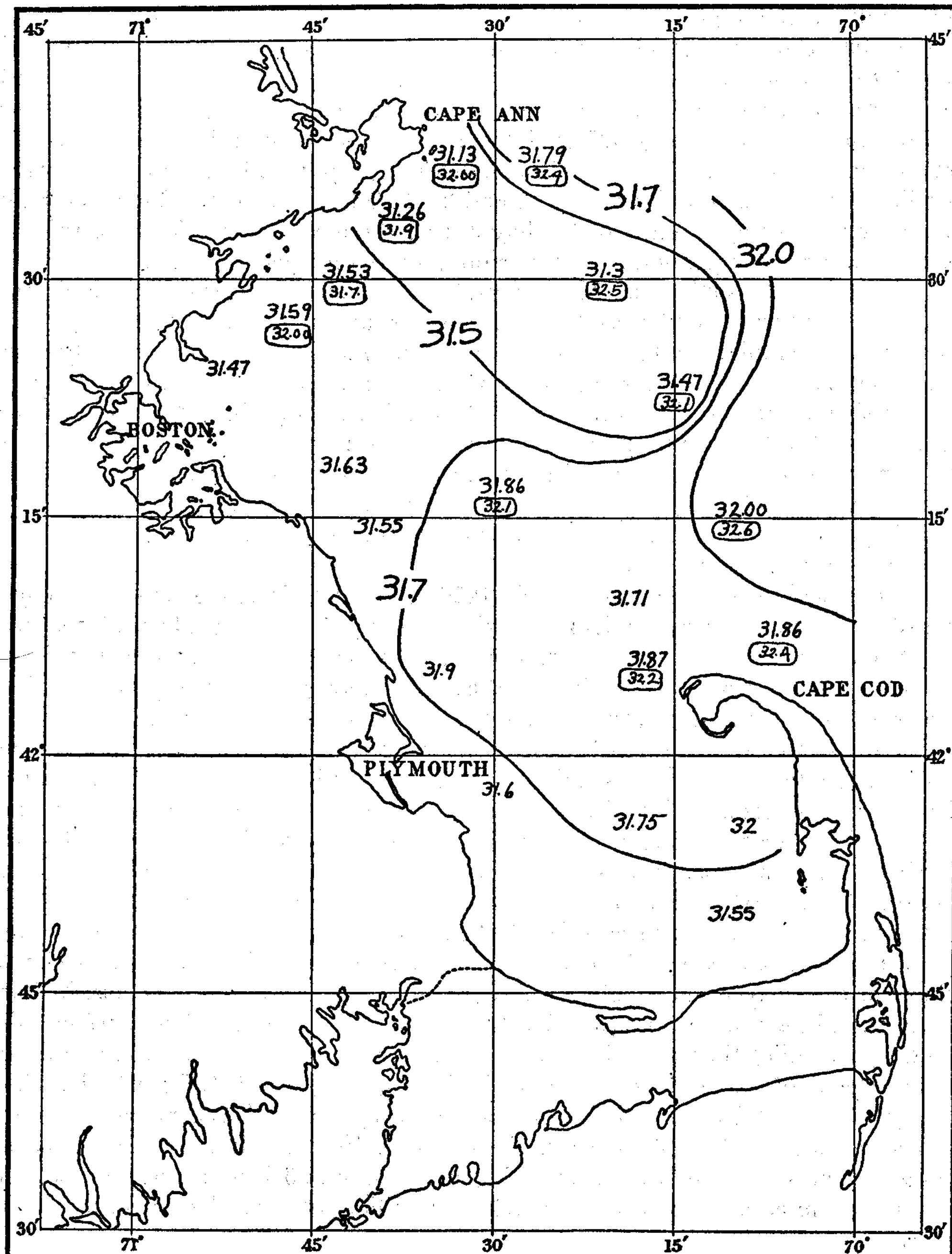

FIG. 102.—Salinity of Massachusetts Bay at the surface (plain figures) and at 40 meters (encircled figures), April 21 to 23, 1925

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]

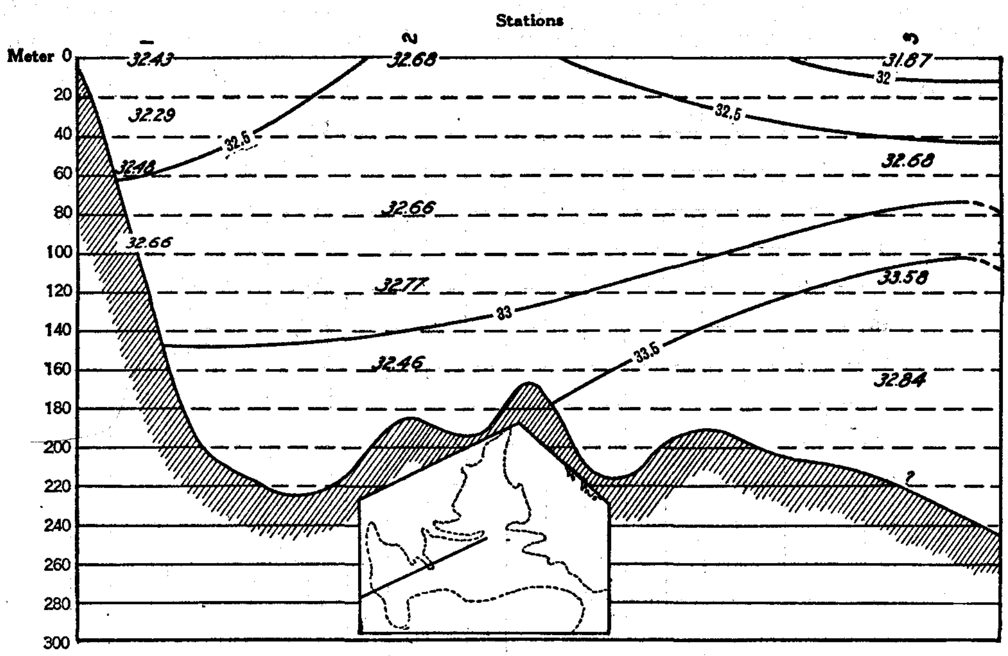

FIG. 103.—Salinity profile running eastward from Cape Cod, March 28 to 29, 1919 (ice patrol stations 1 to 3)

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

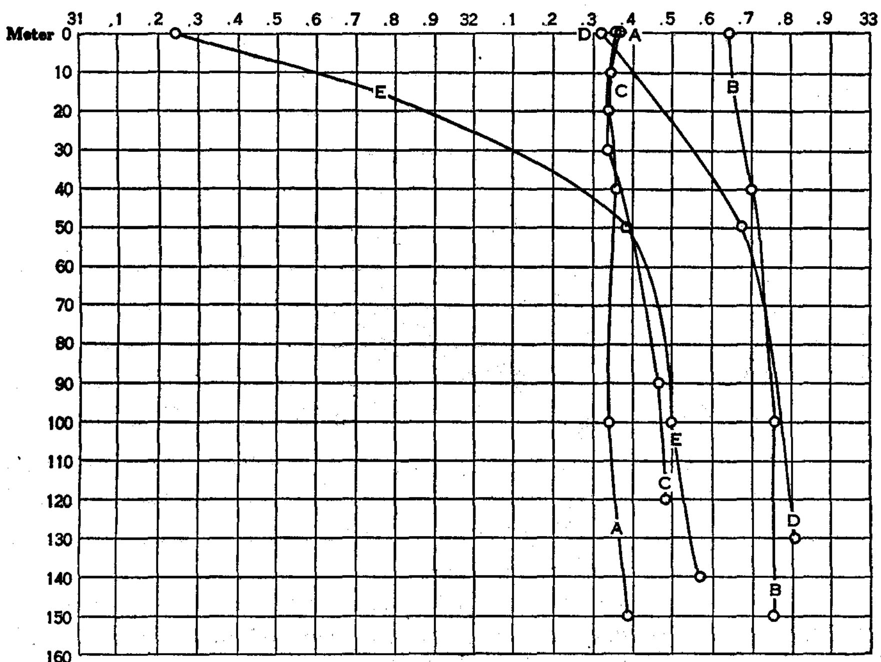

FIG. 104.—Vertical distribution of salinity off Gloucester on March 1, 1920 (A, station 20050), and March 5, 1921 (B, station 10511); for April 9, 1920 (C, station 20090); also for May 4 and August 31, 1915 (D, station 10266, and E, station 10306)

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.

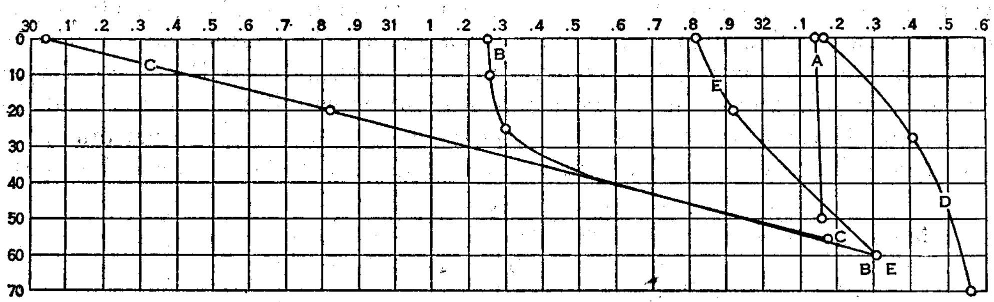

FIG. 105.—Vertical distribution of salinity off Boston Harbor at various seasons. A, March 5, 1920 (station 20062); B, April 6, 1920 (station 20089); C, May 16, 1920 (station 20123); D, August 20, 1913 (station 10106); E, December 29, 1920 (station 10488)

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.

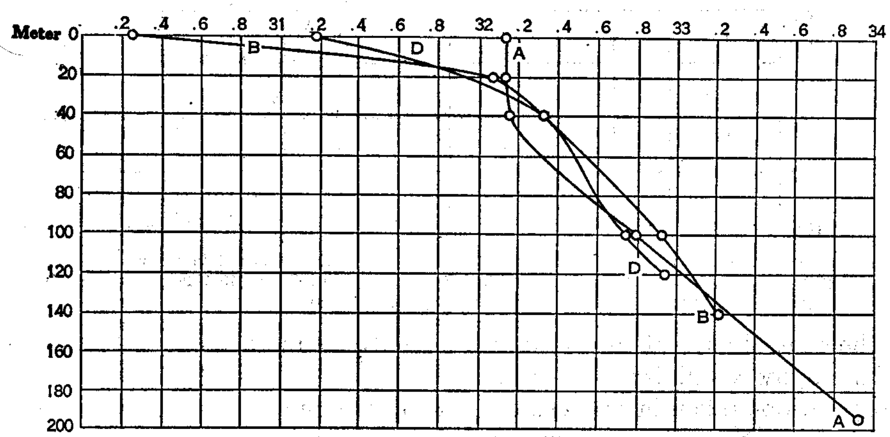

FIG. 106.—Vertical distribution of salinity off northern Cape Cod in various months. A, April 18, 1920 (station 20116); B, May 16, 1920 (station 20125); D, July 14 1913 (station 10213)

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

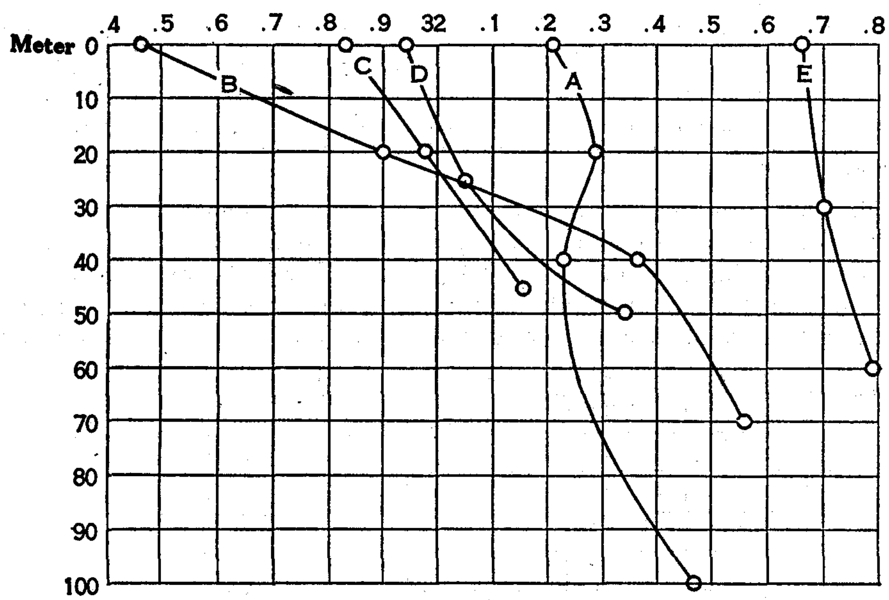

FIG. 107.—Vertical distribution of salinity a few miles off Mount Desert Island in various months. A, March 3, 1920 (station 20056); B, April 12, 1920 (station 20099); C, July 19, 1915 (station 10302); D, August 18, 1915 (station 10305); E, October 9, 1915 (station 10328)

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,

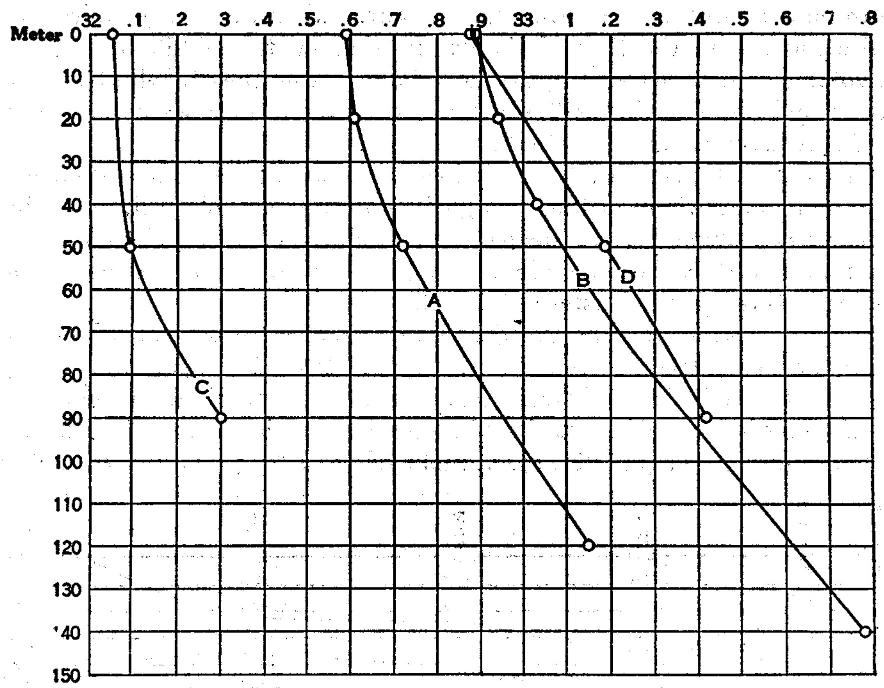

FIG. 108.—Vertical distribution of salinity near Lurcher Shoal. A, March 23, 1920 (station 20082); B, April 12, 1920 (station 20101); C, May 10, 1915 (station 10272); D, September 7, 1915 (station 10315)

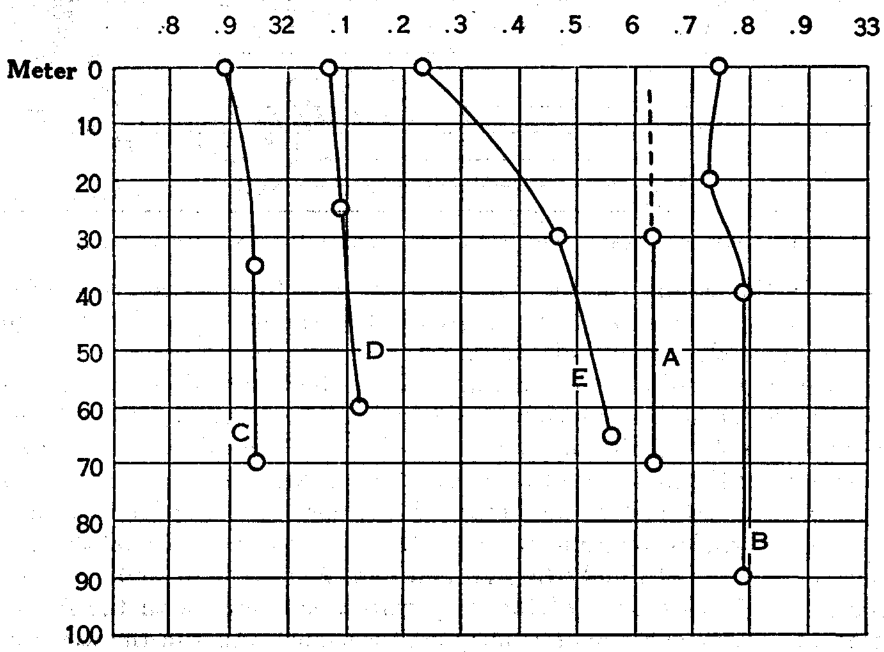

FIG. 109.—Vertical distribution of salinity on German Bank. A, March 23, 1920 (station 20085); B, April 15, 1920 (station 20103); C, May 7, 1915 (station 10271); D, June 19, 1915 (station 10290); E, September 1, 1915 (10311)

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

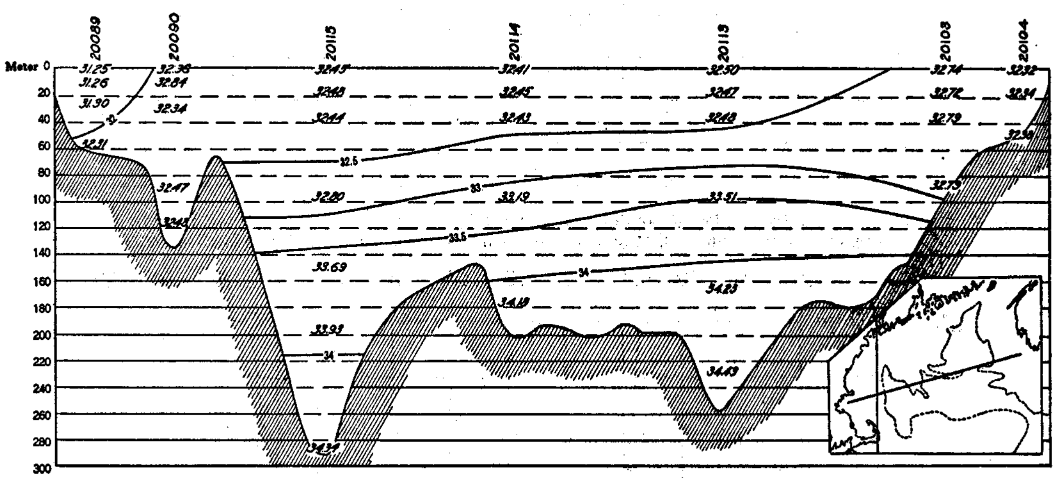

FIG. 110.—Salinity profile running eastward from Massachusetts Bay to the offing of Cape Sable, April 6 to 18, 1920

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).

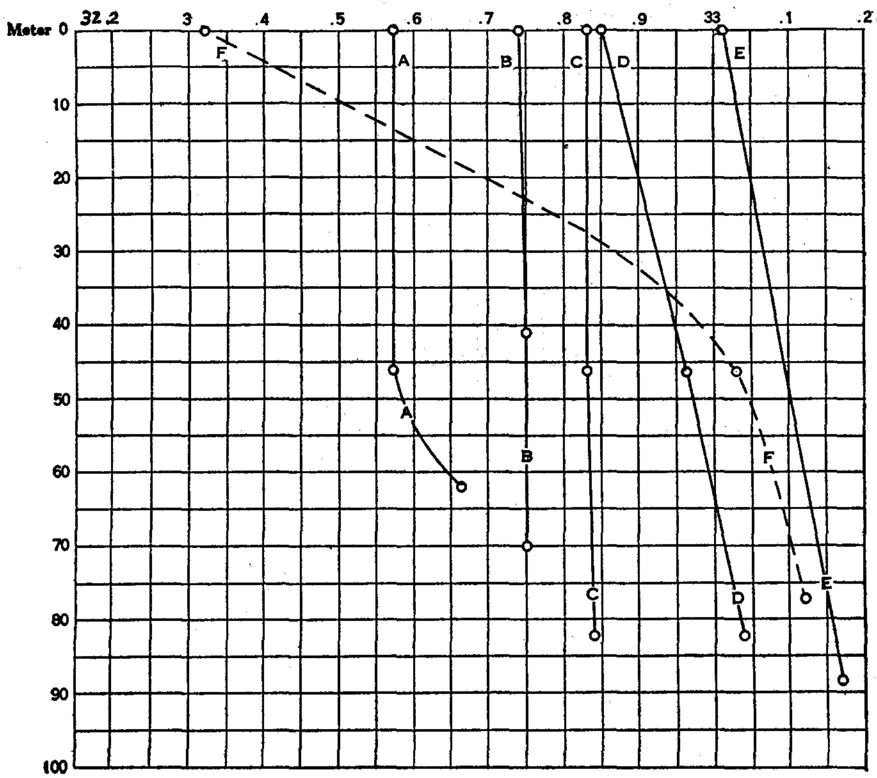

FIG. 111.—Vertical distribution of salinity at the mouth of Massachusetts Bay, off Gloucester, during the winter and spring of 1912–1913. A, November 20 (station 10047); B, December 23 (station 10049); C, February 13 (station 10053); D, March 4 (station 10054); E, March 19 (W. W. Welsh station 1) F April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

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

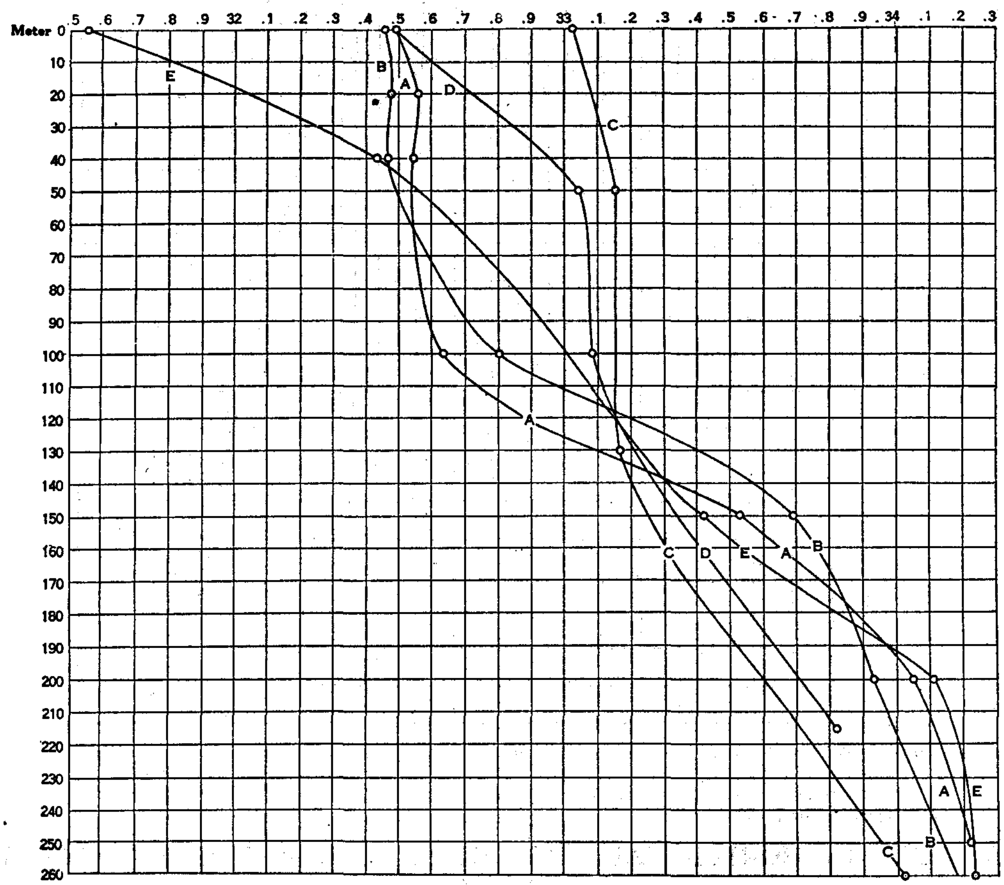

FIG. 112.—Vertical distribution of salinity in the western arm of the basin of the gulf off Cape Ann. A, March 24, 1920 (station 20087); B, April 18, 1920 (station 20115); C, May 5, 1915 (station 10267); D, June 26, 1915 (station 10299); E, August 22, 1914 (station 10254)

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

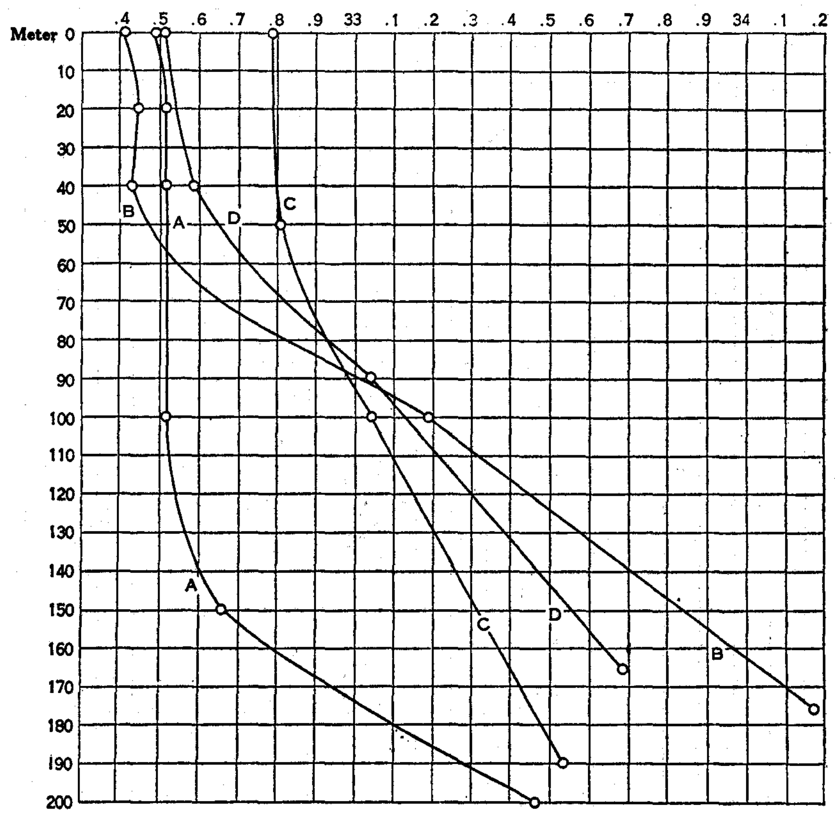

FIG. 113.—Vertical distribution of salinity in the center of the gulf near Cashes Ledge. A, March 2, 1920 (station 20052); B, April 16, 1920 (station 20114); C, May 5, 1915 (station 10268); D, September 1, 1915 (station 10308)

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

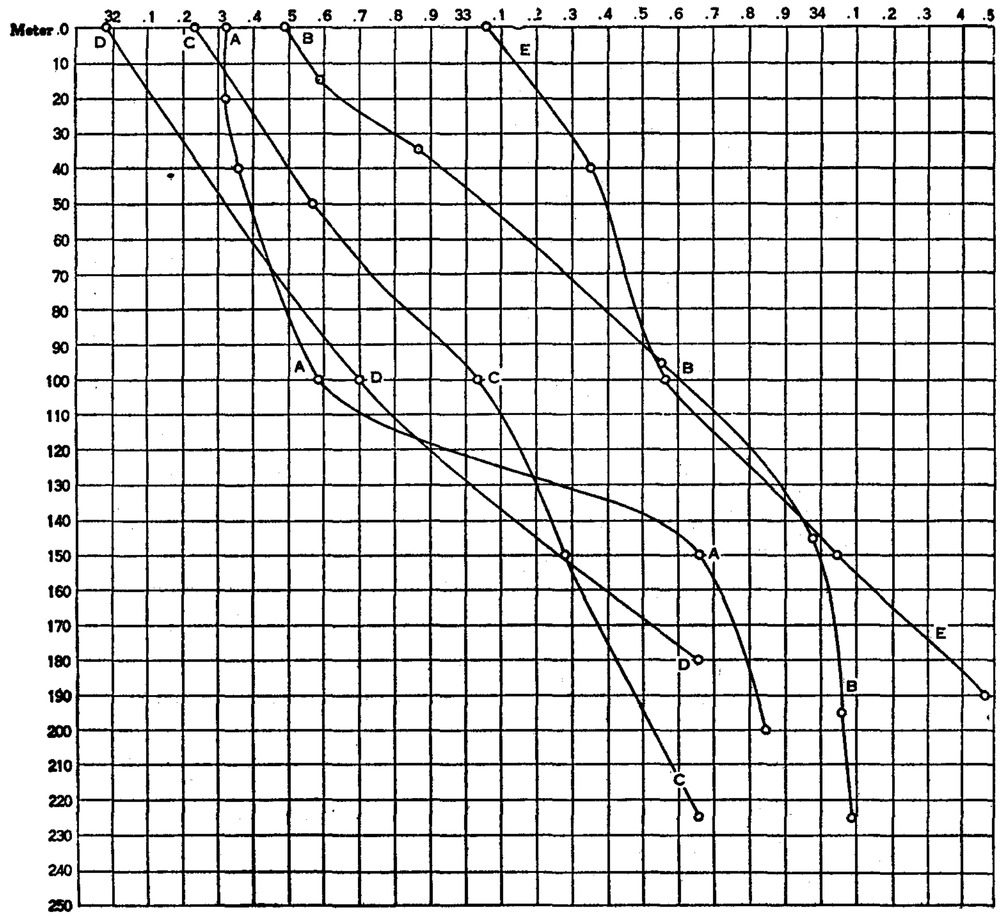

FIG. 114.—Vertical distribution of salinity in the northeastern corner of the gulf. A, March 22, 1920 (station 20081); B, April 12, 1920 (station 20100); C, May 10, 1915 (station 10273); D, June 10, 1915 (station 10283); E, August 12, 1914 (station 10246)

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

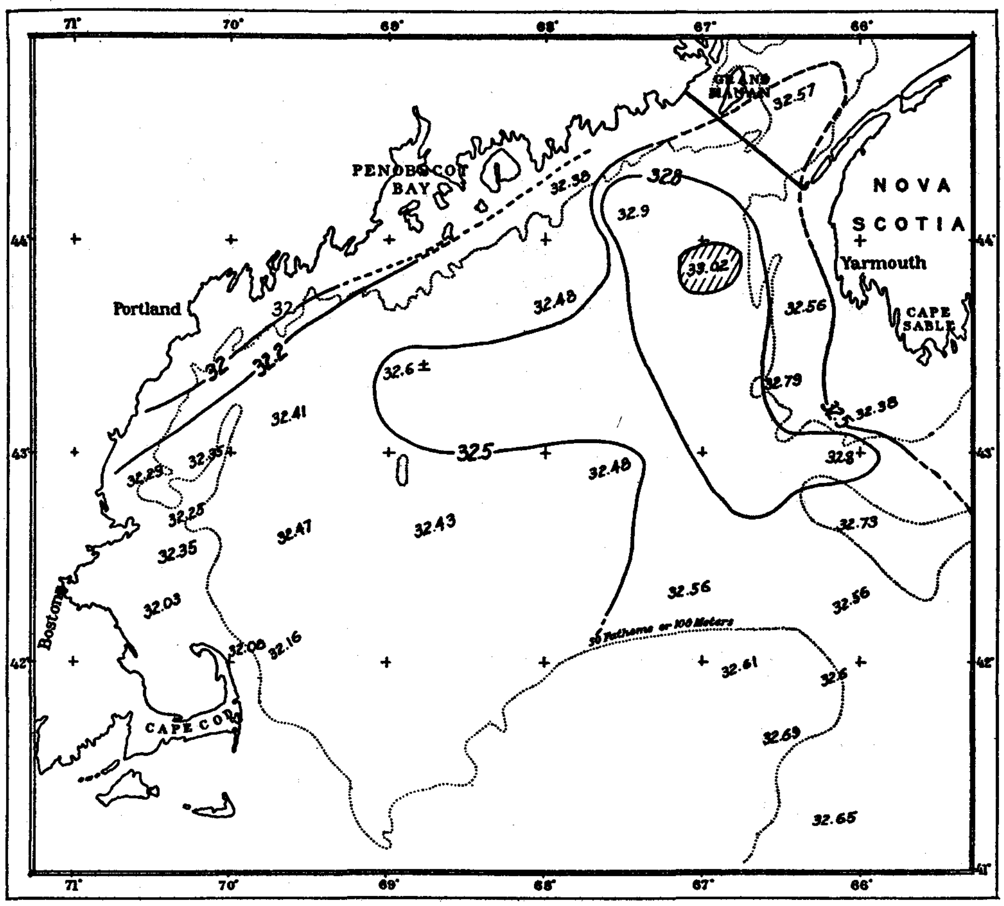

FIG. 115.—Salinity at a depth of 40 meters, April, 1920

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,

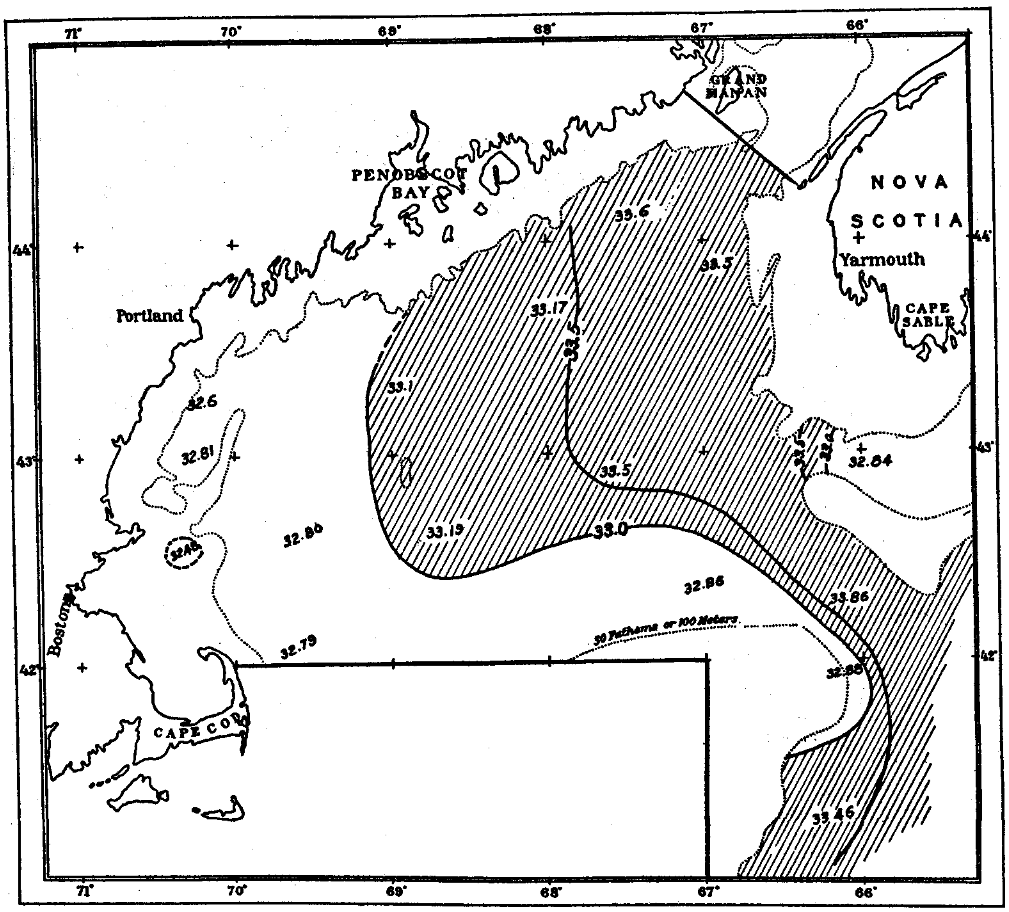

FIG. 116.—Salinity at a depth of 100 meters, April 6 to 20, 1920

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.

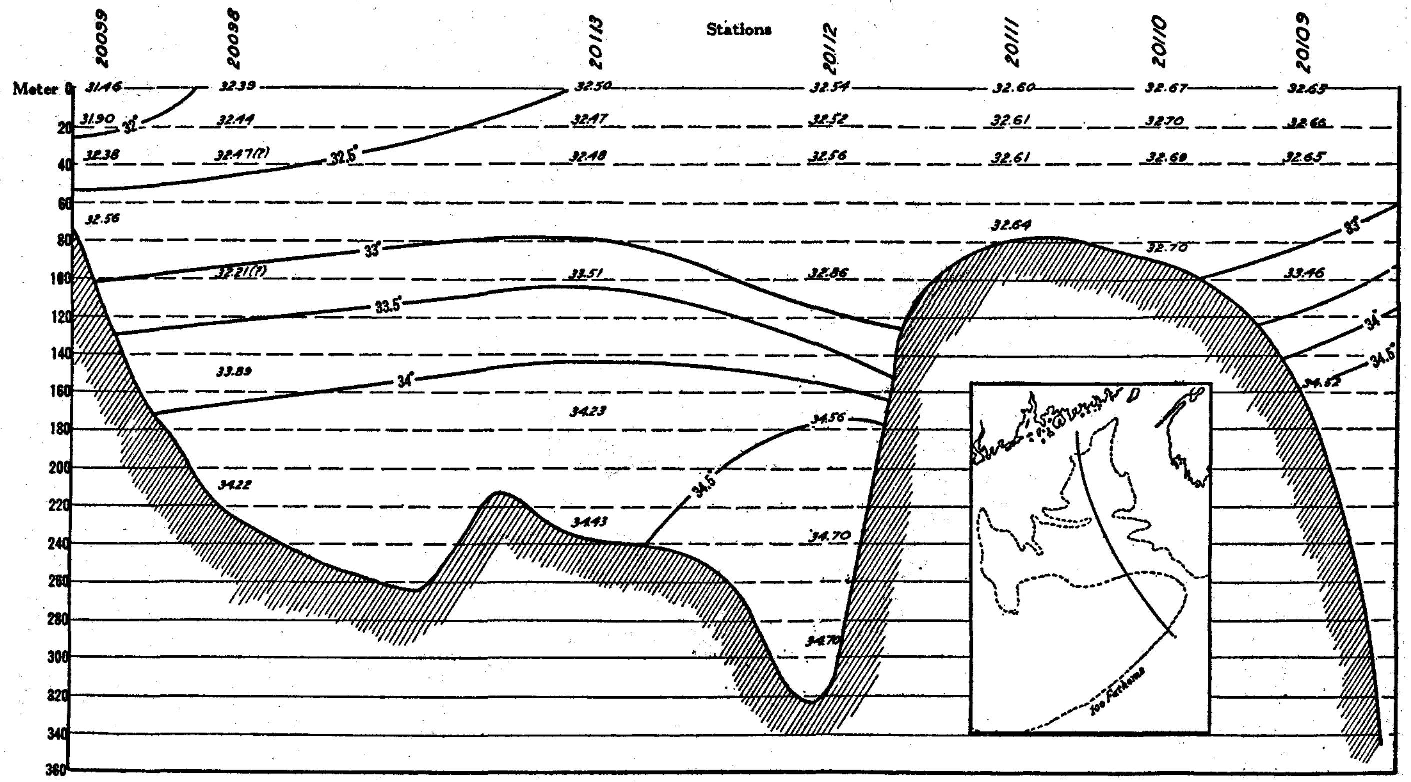

FIG. 117.—Salinity profile, running southward from the offing of Mount Desert Island, across the eastern end of Georges Bank to the continental slope, April 12 to 16, 1920

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

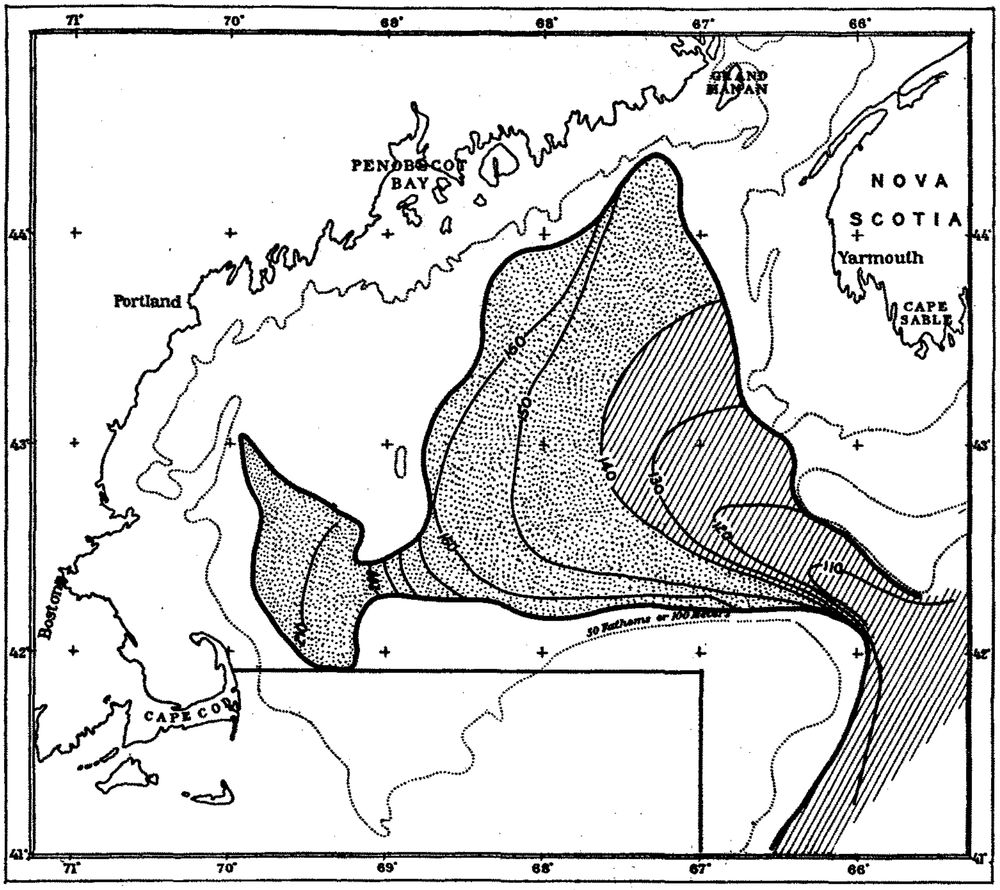

FIG. 118.—Depth below the surface of the isobalobath of 34 per mille, April 6 to 18, 1920

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).

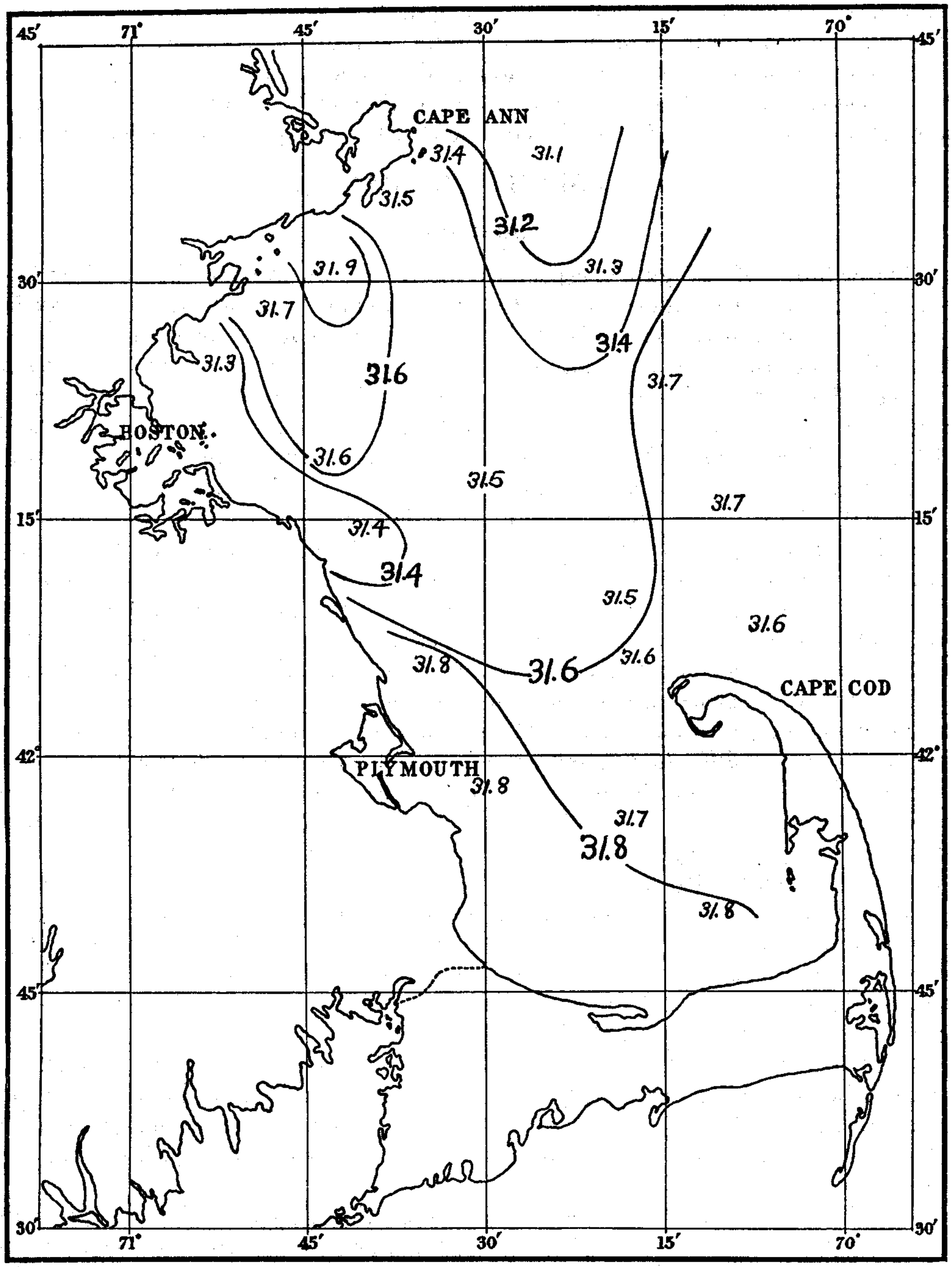

FIG. 119.—Salinity at the surface of Massachusetts Bay, May 20 to 22, 1925, from hydrometer readings

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

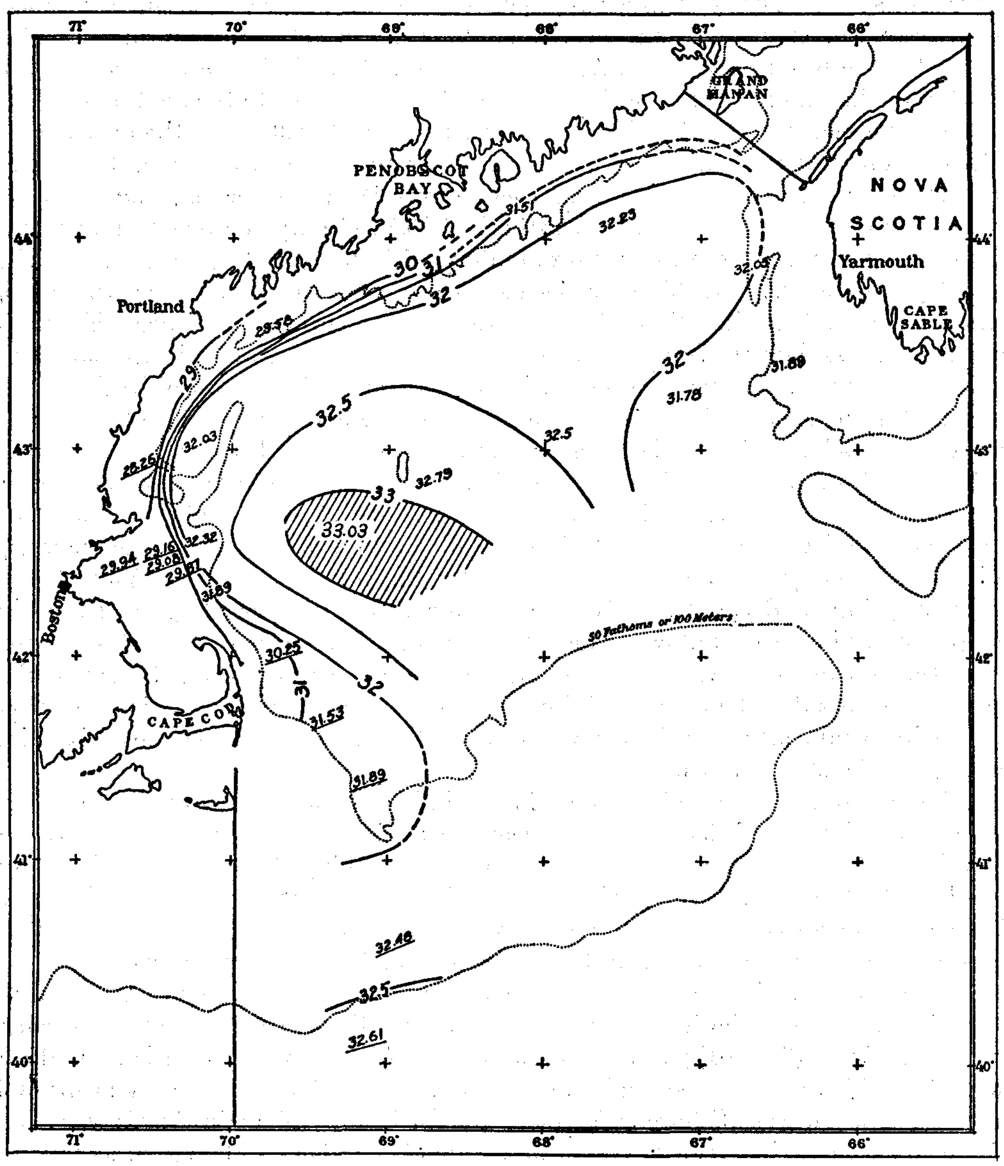

FIG. 120.—Salinity at the surface, May 4 to 14, 1915, combined with May 4 to 17, 1920

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

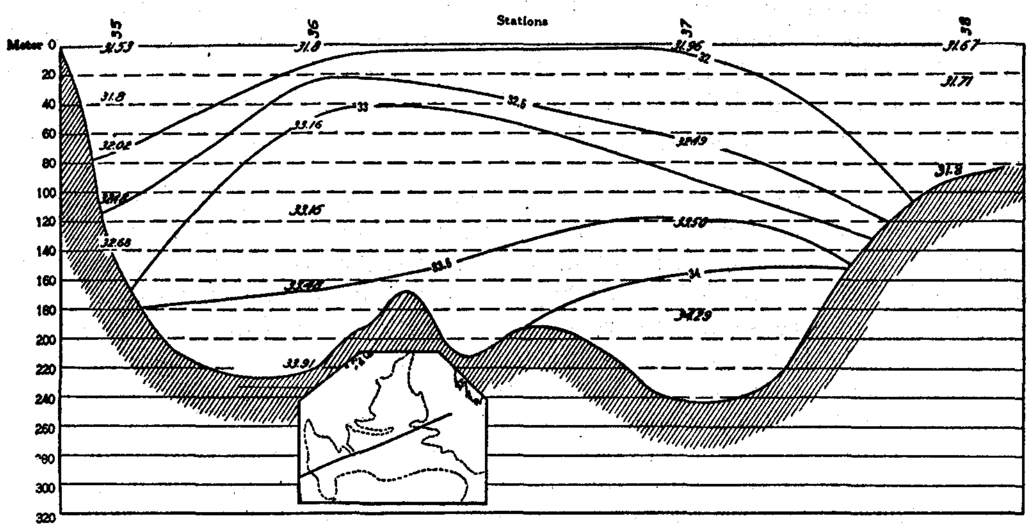

FIG. 121.—Salinity profile running eastward from the offing of Cape Cod toward Cape Sable, May 29 to 30, 1919 (ice patrol stations 35 to 38)

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

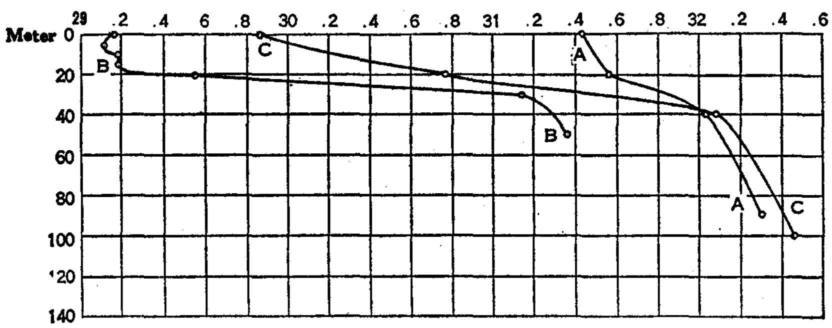

FIG. 122.—Vertical distribution of salinity at the mouth of Massachusetts Bay. A, April 20, 1920 (station 20119); B, May 4, 1920 (station 20120); C, May 16, 1920 (station 20124)

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

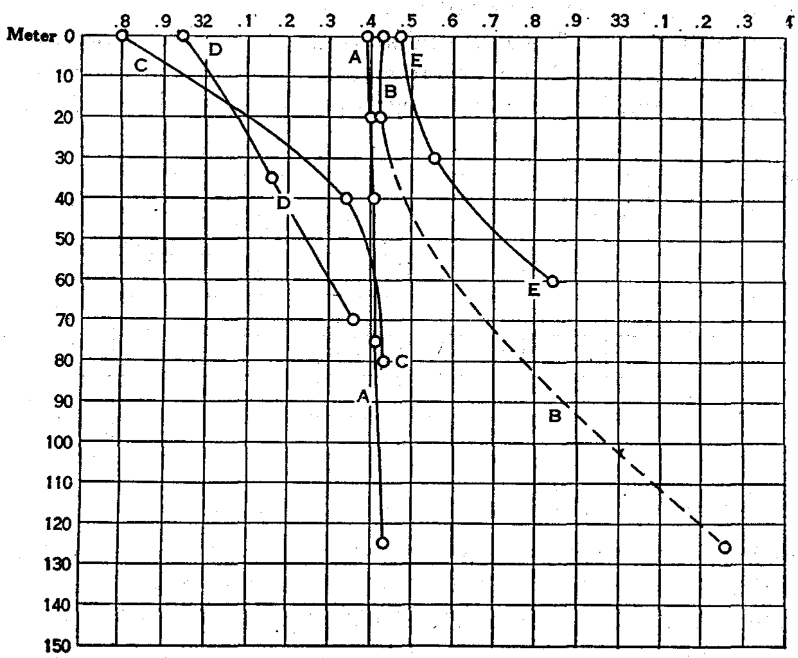

FIG. 123.—Vertical distribution of salinity off Penobscot Bay. A, March 4, 1920 (station 20057); B, April 10, 1920 (station 20097); C, May 12, 1915 (station 10276): D, June 14, 1915 (station 10287); E, October 9, 1915 (station 10329)

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).

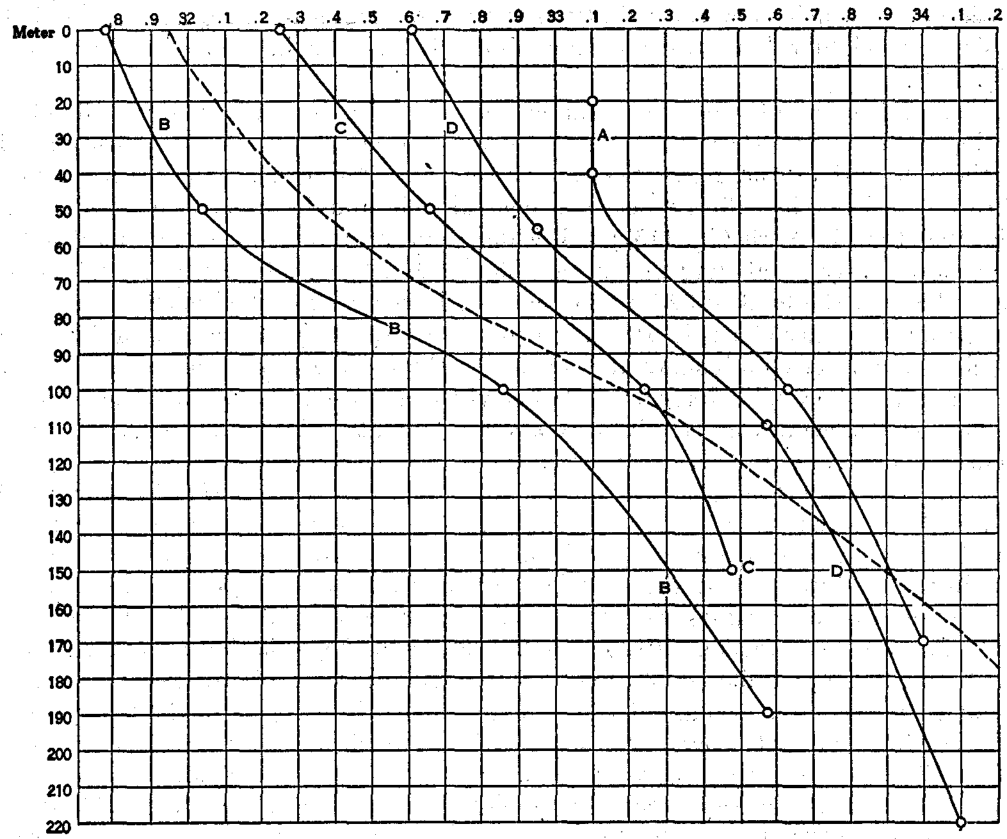

FIG. 124.—Vertical distribution of salinity in the eastern side of the basin of the Gulf of Maine on March 23, 1920 (A, station 20086); May 6, 1915 (B, station 10270); May 29, 1919 (broken curve, ice patrol station 37); June 19, 1915 (C, station 10289); and August 12, 1913 (D, station 10093)

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.