DEPARTMENT OF COMMERCE

BUREAU OF FISHERIES

HUGH M. SMITH, Commissioner

EXPLORATIONS OF THE UNITED STATES COAST AND GEODETIC SURVEY STEAMER "BACHE" IN THE WESTERN ATLANTIC, JANUARY–MARCH, 1914, UNDER THE DIRECTION OF THE UNITED STATES BUREAU OF FISHERIES

OCEANOGRAPHY

By HENRY B. BIGELOW

APPENDIX V TO THE REPORT OF THE U. S. COMMISSIONER OF FISHERIES FOR 1915

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CONTENTS.

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INTRODUCTION.

In connection with the oceanographic and fishery investigations between the Grand Banks and Cape Hatteras which have been prosecuted by the Bureau of Fisheries for a number of years (Bigelow, 1914a–1915), there developed an appreciation of the importance of studying the conditions between the southern Atlantic coast and the Bermudas, Bahamas, and Cuba. As the Bureau of Fisheries had no vessel on the Atlantic coast which was suitable for this offshore work, a request for assistance and cooperation was preferred to the Coast and Geodetic Survey, which also was interested in certain phases of the investigation, particularly the physical hydrography.

The Superintendent of the Survey promptly acquiesced in the suggestion and under an arrangement for an equitable division of expenses, the Coast and Geodetic Survey steamer *Bache*, under the command of Capt. C. C. Yates, was assigned to the duty. The investigations were under the direction of the Bureau of Fisheries, W. W. Welsh, assistant in that Bureau, having immediate charge. The cruise lasted from January 20, 1914, to March 23 of the same year.

The course of the *Bache* (see chart) led from Chesapeake Bay to the oceanic basin in longitude 73° 15′, thence south to latitude 32° 30′, and from that point to Bermuda. Sailing from Bermuda on February 17, she ran 200 miles southwest, to latitude 29° 30′, then west to a point 140 miles north of the Bahamas, and south to Nassau. Three sections were then run across the Straits of Florida, viz, Key West to Habana, Founey Rocks (Cape Florida) to Gun Cay, and Jupiter Inlet to the northern end of the Little Bahama Bank (Mar. 13–21); and, finally, a line thence to connect with the Bermuda-Bahama line. Serial oceanographic observations were taken at 38 stations and surface temperatures and water samples at 19 additional stations. The temperatures [a] were taken with reversing thermometers of the latest type, with auxiliary thermometers to give the

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[a] Temperatures are centigrade.

temperature of the detached thread of mercury at the moment of reading. The water samples were collected with Ekman reversing water bottles (Ekman, 1905b) and with the Bigelow stopcock water bottle (Bigelow, 1914a). Unfortunately, the former proved unreliable in the strong currents in which much of the work was carried on; consequently a number of the water samples are untrustworthy, and such have been omitted from the table of salinity (p. 55).

The limitation of the gear on the *Bache* made it impracticable to work deeper than 1,800 meters. Only occasionally were water samples or temperatures taken on the sounding wire at greater depths; but down to 1,800 meters the records are sufficiently full to afford a satisfactory survey of both temperature and salinity.

Throughout the cruise the weather was most unfavorable. There was a constant succession of gales, occasionally of almost hurricane strength, taxing vessel and personnel to the utmost.

The salinities were executed in the laboratories of the United States Bureau of Fisheries at Washington.

THE ATLANTIC WATER.

The *Bache* stations give a survey of the upper 1,800 fathoms between Chesapeake Bay and Bermuda; from Bermuda to a point 200 miles to the southwest; and between the latter and the northern end of the Bahama Bank. (See chart.) Off Chesapeake Bay the surface temperature (fig. 1) rose suddenly from about 12° over the 200-meter contour to 21.5° 80 miles farther east. This very warm water was evidently only a very narrow band, for as a rule the surface water, as far as Bermuda, was 18.8°–19.5°. Close to Bermuda the surface temperature was 18°–19°; but about 200 miles farther south it rose to 21°, and on the line to the Bahamas it was constantly 20° or warmer, except between longitude 67° 30′ and 71°, where cooler water was encountered. North of the Bahamas the surface water warmed to 23°; and it was even warmer, 23.6°, at the mouth of the Straits of Florida, off Jupiter Inlet. These observations show that there were four fairly distinct temperature zones, as outlined on the chart (fig. 1): First, the coast water off Chesapeake Bay, 15° or colder, which probably extends, though with constantly rising temperature, to Savannah; second, the general warm water of the Antilles drift, with temperatures warmer than 20°, which swings northeastward parallel to the coast, reaching latitude about 36° in January and February; third, the superheated water coming from the Gulf of Mexico, via the Straits of Florida, which gradually merges with the Atlantic water; and, fourth, a comparatively cool region west of Bermuda, no doubt continuous with the colder water farther north. All this, of course, agrees in its main lines with the earlier temperature charts (Agassiz, 1888; Berghaus, 1891; Deutsche Seewahrte, 1882) and the correspondence with Schott's (1912) chart for the month of February is extremely close. Thus there is no reason to suppose that the surface temperatures in the winter of 1913–14 were anything but normal.

In the eastern half of the region surface salinity (fig. 2) agreed very well with surface temperature, being lower than 36.5°/₀₀ to the west and southwest of Bermuda; with the curve for 36.5°/₀₀ nearly paralleling the curve of 20° temperature here, and the curve of 36.6°/₀₀

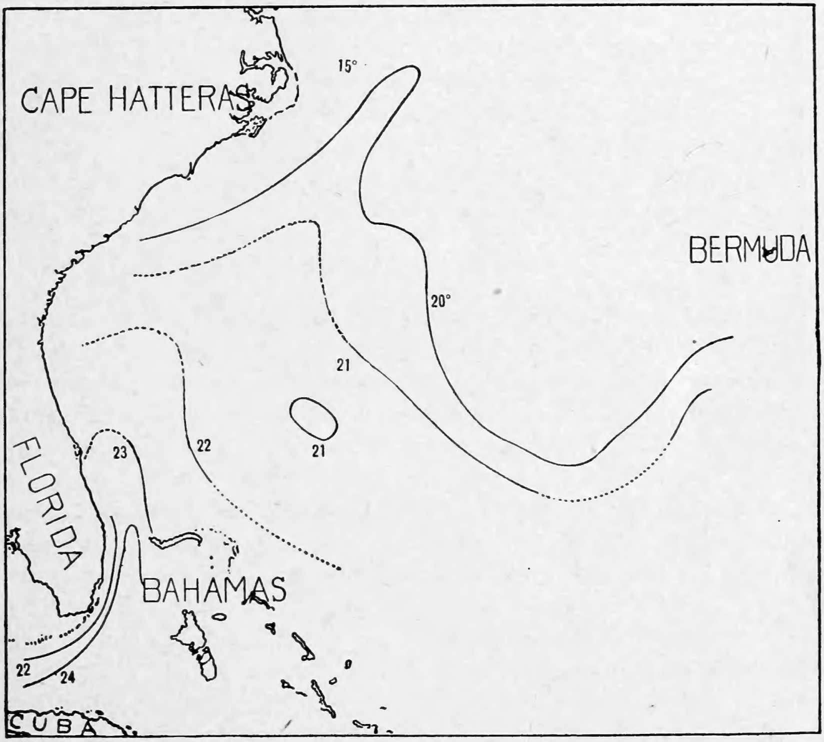

FIG. 1.—Surface temperature of the western Atlantic, coast of United States to Bermuda, January to March, 1914.

that for 21°. Water salter than 36.5°/₀₀ formed a very well-defined tongue swinging northeastward from the Bahama Bank, the curve for 36.4°/₀₀ paralleling the coast line, with water fresher than 35°/₀₀ next the land off Cape Hatteras, and probably as far south as northern Florida. The 36.5°/₀₀ water may be definitely classed as the continuation of the Antilles current, thus agreeing with the temperature curves; the slightly fresher water (36–36.4°/₀₀) west of it as largely Florida current water; and the still fresher water next the coast north of Florida as coast water.

Schott's (1902) chart of average surface salinity for the year shows the same northward tongue of 36.5°/₀₀ or Antilles water, as is to be seen on the *Bache* chart (fig. 2); but most of the critical area is blank for want of data. The records since collected by the international committee for the exploration of the sea (1909, 1910, 1911) add very little to our knowledge of the region in question, those for this general part of the Atlantic being chiefly limited to a line from the neighborhood of Bermuda to Jamaica. In short, previous salinity records, at least by modern methods, are so scanty for

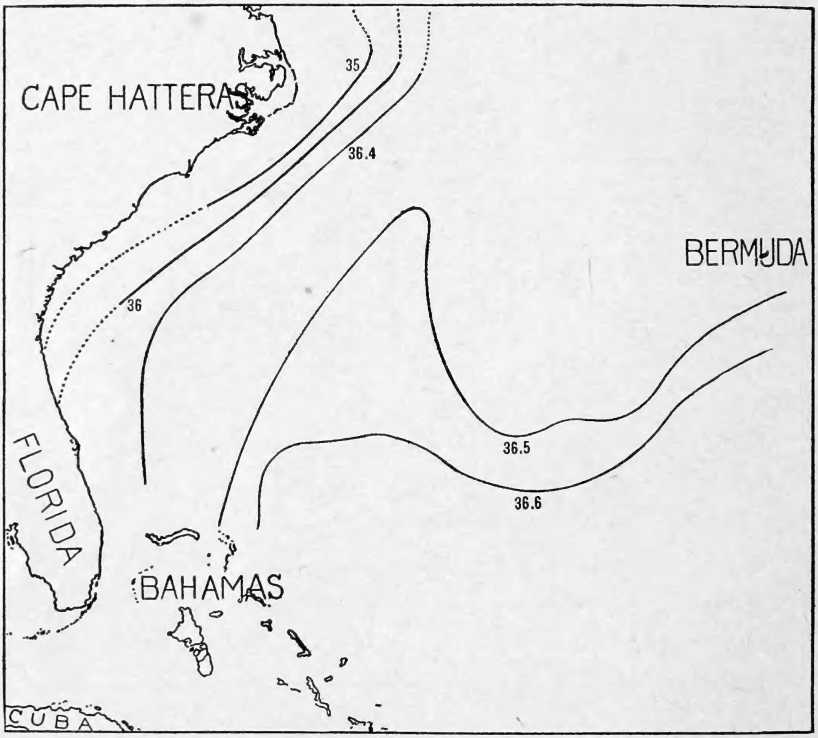

FIG. 2.—Surface salinity of the western Atlantic, coast of United States to Bermuda, January to March, 1914.

the region crossed by the *Bache* that it is impossible to state whether the conditions which she encountered there are characteristic of the winter season.

Typical examples of the serial temperatures and salinities taken by the *Bache* between the continental slope and Bermuda, and between Bermuda and the Bahama Bank, which are given in full in the tables (p. 55), are represented graphically in the accompanying sections (fig. 3–10). The temperatures all agree in showing a general cooling from 19°–22° on the surface to about 4° at 1,800 meters. The curves southwest of Bermuda are all approximately parallel, though with slight variations in the middepths, and especially near the surface. Between Bermuda and the Chesapeake (fig. 3) there are great variations in temperature station to station, between 700 and 1,400 meters, though the temperature was comparatively uniform at 1,800 meters and between 700 meters and the surface. This was also the case, though to less degree, north and northeast of the Bahamas (fig. 6). On the whole the middepths were warmest

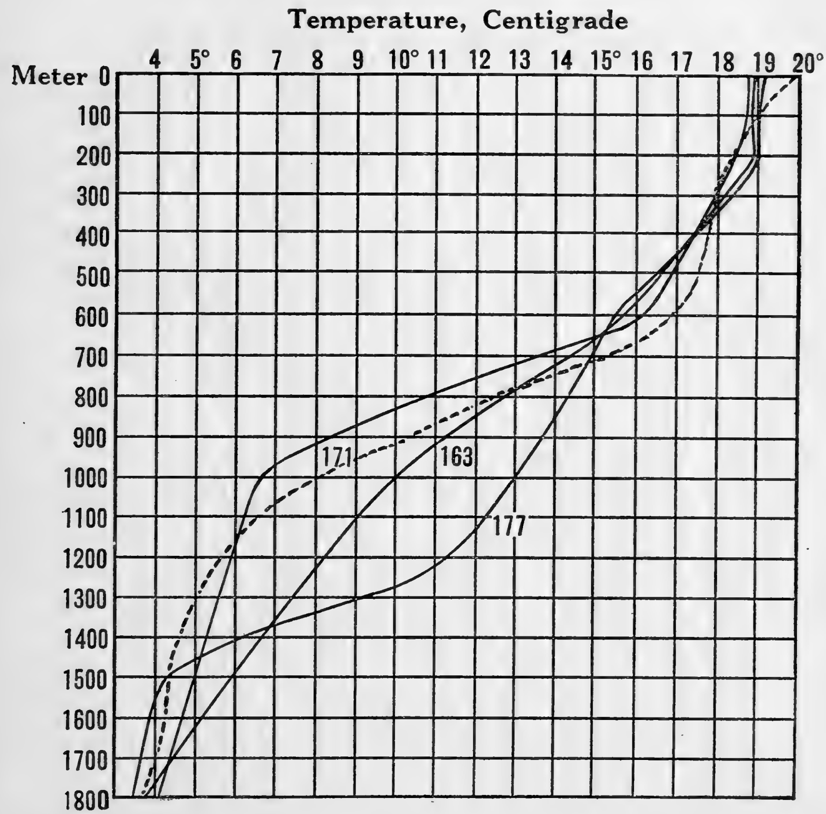

FIG. 3.—Temperature sections between the continental slope off Chesapeake Bay and Bermuda, stations 10163, 10171, 10177; and *Challenger* station 37, 40 miles west of Bermuda, April 24, 1878 (......).

west of Bermuda (station 10177), coldest north of the Bahamas (stations 10210–10212) and in the northeast Providence Channel (station 10196), if we omit for the moment the very much colder water over the continental slope. In the upper layers, between, say, 300 meters and the surface, the Antilles water was warmest, this relationship of the various stations to one another being more clearly revealed by the profiles (fig. 11, 12, 15) and charts of temperature at different levels (fig. 17, 18, 20).

The course of the *Challenger* in 1873 crossed that of the *Bache* at Bermuda, allowing a direct comparison of the vertical distribution of temperatures for 1873 (Murray, 1884) and 1914 in that neighborhood. The temperature series taken by the *Challenger* about 260 miles south of Bermuda in March of that year (*Challenger* station 29),

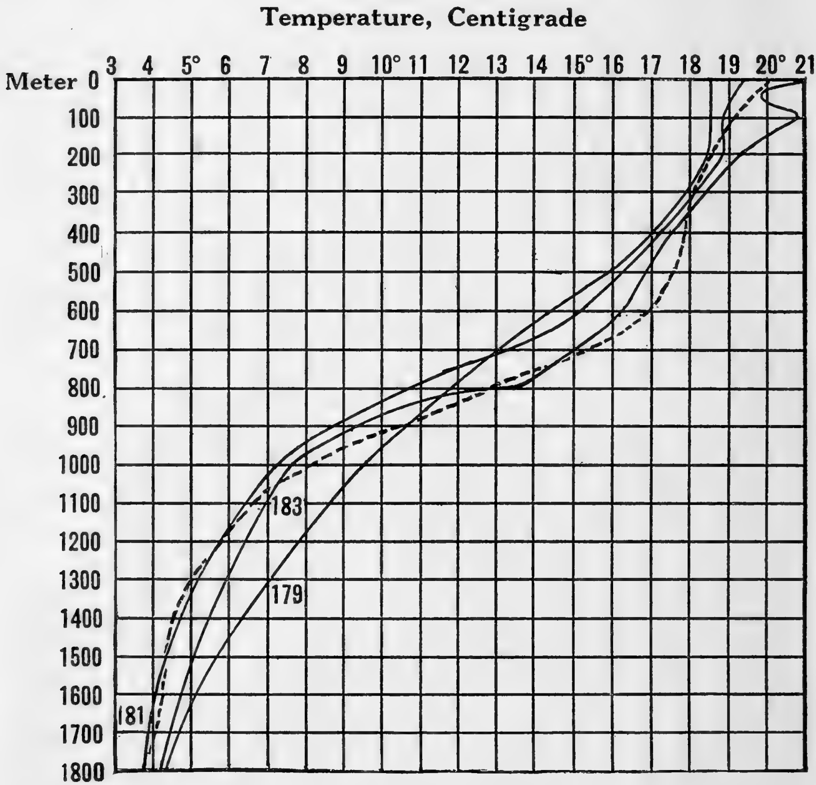

FIG. 4.—Temperature sections on a line running 200 miles southwest from Bermuda; stations 10179, 10181, 10183; and *Challenger* station 37 (......).

agrees very closely with the serial at *Bache* station 10185, except near the surface, as shown by the following table:

Depth in meters.	Bache station 10185.	Bache station 10212.	Challenger station 29.	Depth in meters.	Bache station 10185.	Bache station 10212.	Challenger station 29.
	° C.	° C.	° C.		° C.	° C.	° C.
0	19.8	20.75	22.2	1,000	7.1	5.62	5.8
100	19.55	20.5	20.3	1,100	6.2	5	4.7
200	18.6	19.2	18.2	1,200	5.4	4.6	4.6
300	17.3	17.77	17.5	1,300	4.8	4.4	4.5
400	16.4	16	16.7	1,400	4.44	4.2	4.5
500	15.5	14.62	15.5	1,500	4.1	4	4.2
600	14.4	12.8	13.8	1,600	3.9	3.8	4
700	11.7	10.8	11.5	1,700	3.8	3.7	3.9
800	9.67	9	9	1,800	3.77	3.67	3.9
900	8.2	7	7.3				

Between 200 and 800 meters, and again below 1,200 meters, the greatest difference is only 0.6°, hardly more than the probable error of the curves from which the table is constructed. Above 200 meters the *Challenger* series is decidedly the warmer; but this difference is probably due to the geographic location of the stations, the temperature of 1914 (fig. 1) suggesting that in that year also the surface reading would have been above 21° at the locality of the *Challenger* station. Between the 800 and the 1,200 meter levels the temperatures were from 0.6° to 1.5° lower in 1873 than in 1914; but here again

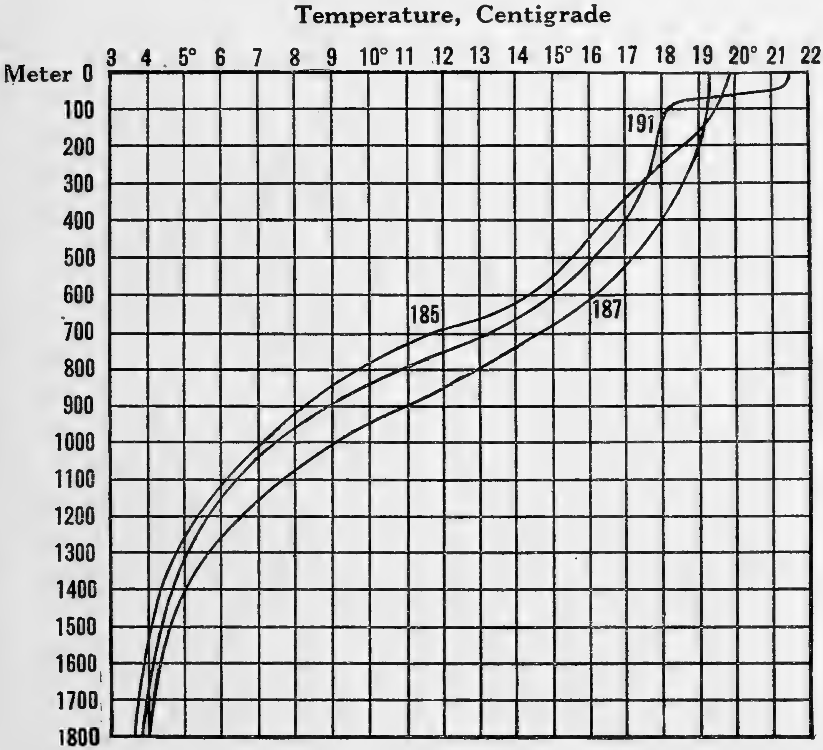

FIG. 5.—Temperature sections between Bermuda and the Bahama bank; stations 10185, 10187, 10191.

it may be the difference in geographic location which is responsible, the lower temperature of the *Challenger* station at this depth being an indication of the general and well-known upwelling of abyssal water toward the Equator. Indirect evidence to this effect is afforded by the fact that these *Challenger* temperatures agree almost exactly, below 800 meters, with *Bache* station 10212 on nearly the same latitude north of the Bahama Bank, and they do not differ from the latter by more than 1.4° at any depth, as illustrated in the preceding table (p. 10).

The temperatures a few miles south of Bermuda agree very closely for the two years, one being slightly colder at some depths, the other at other depths, as illustrated by the following table, constructed

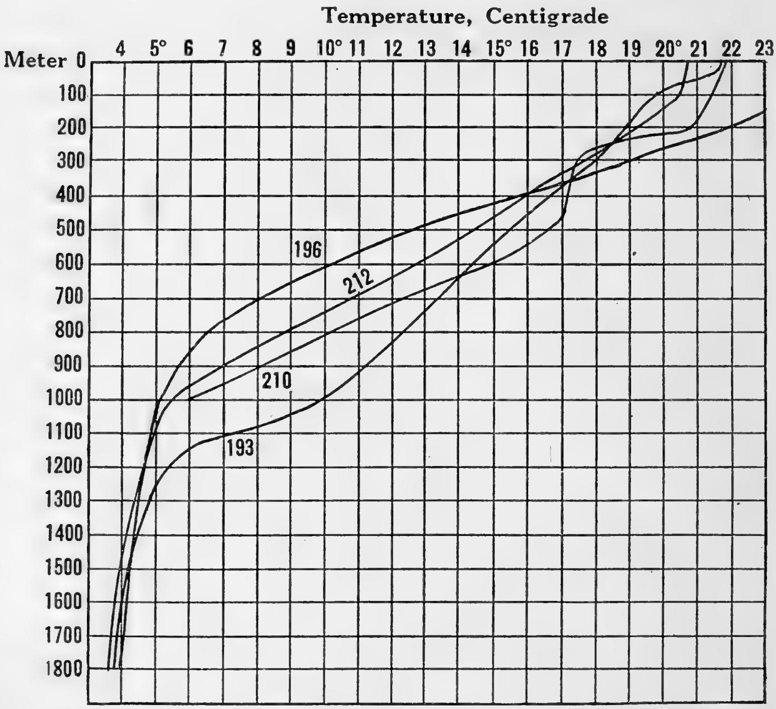

FIG. 6.—Temperature sections in the oceanic basin east of the Bahama Bank; stations 10193, 10210, 10212; and in the northeast Providence channel, station 10196. (Down to 1,800 meters only.)

from the temperature curves for *Challenger* station 57b, 20 miles southwest of Bermuda (Murray, 1884), and *Bache* station 10181:

Depth in meters.	Bache station 10181.	Challenger station 57*b*.	Difference.	Depth in meters.	Bache station 10181.	Challenger station 57b.	Difference.
	° *C.*	° *C.*	° *C.*		° *C.*	° *C.*	° *C.*
0	19.37	22.78	+3.41	1,000	7.38	6.5	−.88
100	18.78	19.7	+.92	1,100	6.5	5.3	−1.2
200	18.89	18.5	−.39	1,200	5.7	4.7	−1
300	18.2	17.8	−.6	1,300	5.2	4.4	−.8
400	17.13	17.2	−.07	1,400	4.88	4.2	−.68
500	16.3	16.6	+.3	1,500	4.4	3.9	−.5
600	15.2	15.4	+.2	1,600	4	3.8	−.2
700	13.2	13.5	+.3	1,700	3.9	3.7	−.2
800	10.7	11.2	+.5	1,800	3.89	3.5	−.3
900	8.7	9	+.3				

The only important difference—the warmer surface in 1873—is no doubt due to the fact that observations were taken in May, 1873, and in February, 1914.

Off the west slope of the Bermudas the temperature of the mid-depths was much higher in 1914 (*Bache* stations 10173–10177) than in 1873, though in the abyss and above about 700 meters there was little difference (fig. 3). This divergence seems to have been a local, not a general, phenomenon, for the two *Challenger* stations within 100 miles west and northwest of Bermuda (no. 37 and 38) agree much more closely with *Bache* station 10171 (fig. 3). So far as these records go there seems to have been little difference in the tempera-

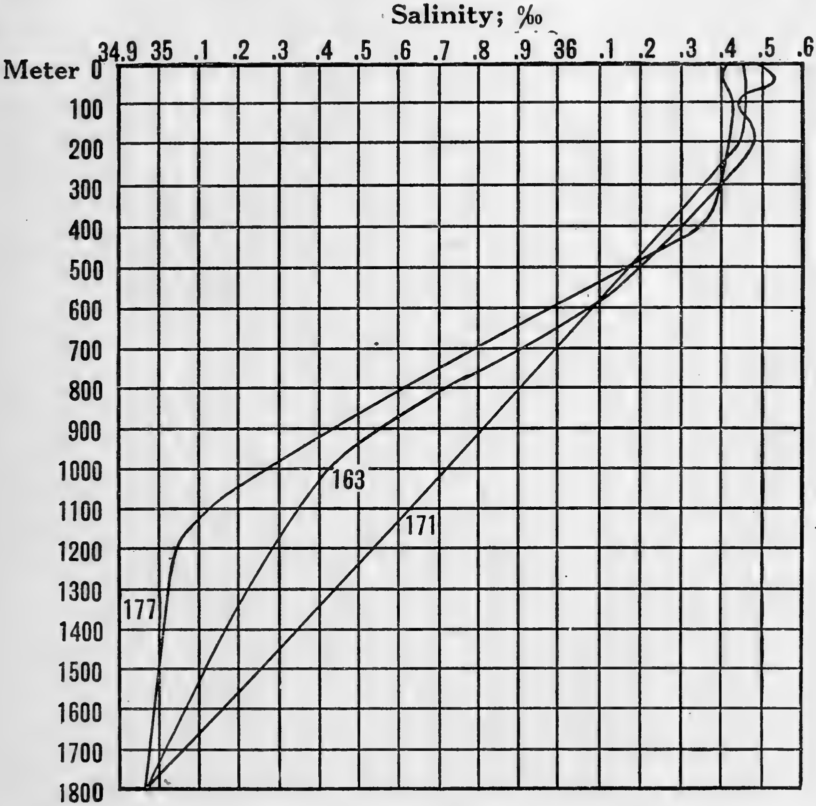

FIG. 7.—Salinity sections between the continental slope off Chesapeake Bay and Bermuda; stations 10163, 10171, 10177.

tures of 1873 and 1914 in this part of the Atlantic as a whole; but the water in the neighborhood of Bermuda was much more uniform in 1873 than in 1914, when there was a very considerable variation of temperature at 800 to 1,200 meters between stations west (10177) and others south of the island.

The salinity curves, like those for temperature, all approach a nearly uniform value at 1,800 meters, viz, 34.9–35°/₀₀; and, like the temperatures, they show the greatest variations in the middepths between 500 to 1,500 meters, the extreme range at 1,200 meters being only 7°/₀₀ (34.8–35.5°/₀₀). The salinity of the mid-depths, like the temperature, was highest west of Bermuda, where water of 35.2 per cent was encountered at about 1,500 meters; lowest north and northeast of the Bahama Bank (stations 10193, 10210, 10212) and in the northeast Providence Channel (station 10196), where water of this salinity was within 700–800 meters of the surface. So far as I can learn, no serial salinities have pre-

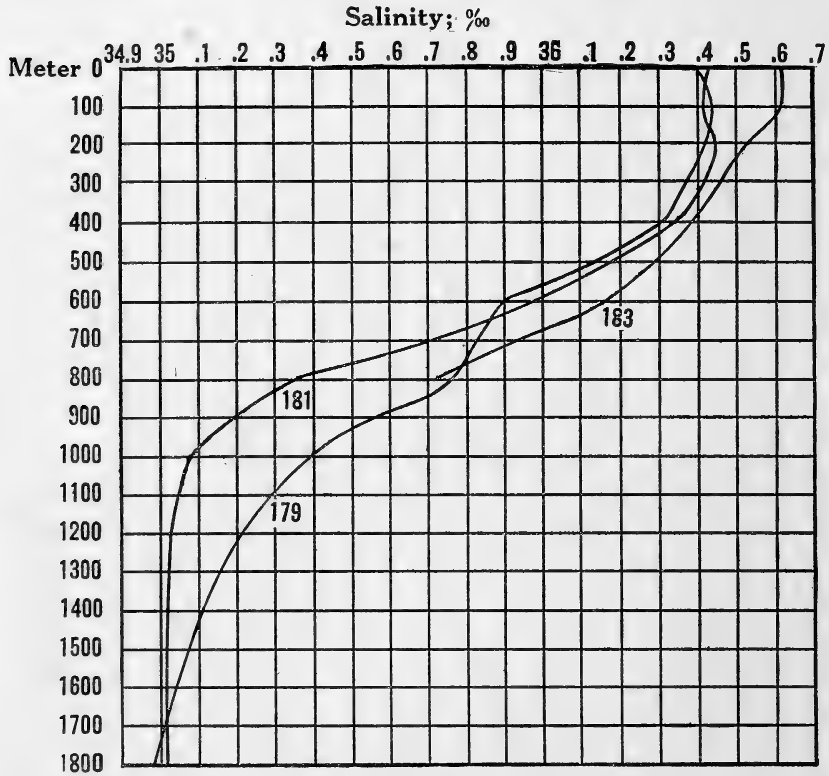

FIG. 8.—Salinity sections on a line running 200 miles southwest from Bermuda; stations 10179, 10181, 10183.

viously been taken by modern methods in the region in question, the *Challenger* records being all open to suspicion because of unreliable water bottles.

TEMPERATURE AND SALINITY PROFILES.

The profile from Chesapeake Bay to Bermuda (fig. 11) is necessarily interrupted between stations 10161 and 10163, owing to the zigzag course followed. (See chart.) On this line water warmer than 20° was confined to a narrow surface belt just east of the 1,800-meter contour on the continental slope (station 10161), with a secondary band at station 10165; otherwise the temperature was very uniform east of station 10163 above 650 meters, the curve for 15° being almost horizontal at that level, to swing up to the surface near the land as described elsewhere (p. 47). And, again, the temperature was nearly uniform at 1,800 meters east of station 10163. But in the middepths there is a very pronounced upwelling of cold water, revealed by the curves for 5° and 10°, in the center of the profile, between 800 and 1,600 meters. At the western (landward) end of the profile all the curves swing sharply upward, showing a very pronounced

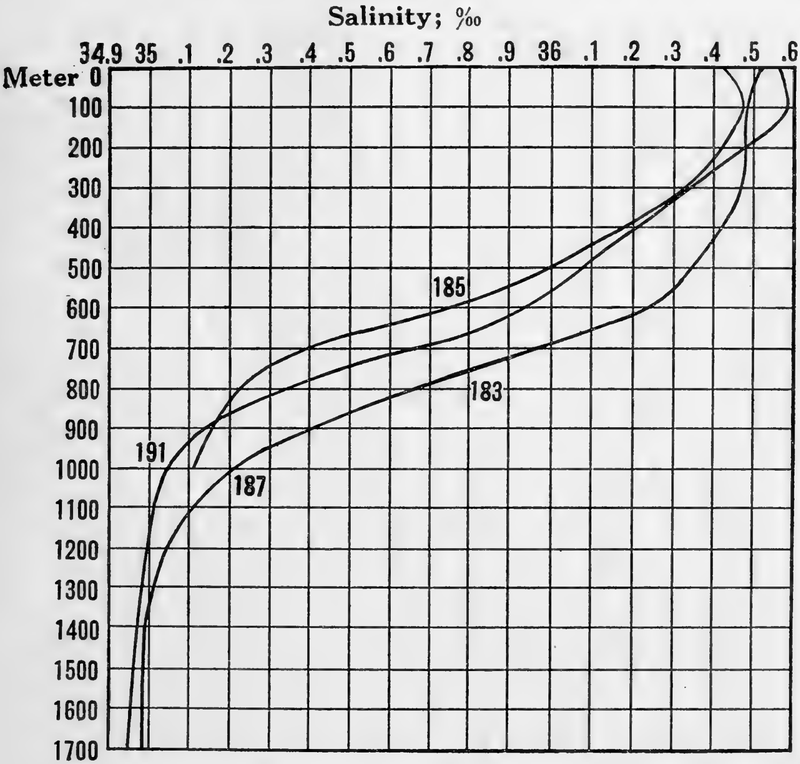

FIG. 9.—Salinity sections between Bermuda and the Bahamas; stations 10183, 10185, 10187, 10191.

banking up of cold water against the continental slope, which need be merely mentioned here, being discussed at length on page 47, and there was evidently a minor banking up of abyssal water against Bermuda below 1,200 meters. Down to the 700-meter level salinity (fig. 12) agrees closely with temperature, the curve for 36°/₀₀ practically coinciding with 15°, the warm surface water at station 10164 finding its counterpart in high salinity (36.5°/₀₀). On the continental slope the successive curves for salinity dip, like those for temperature, very steeply from west to east—i. e., they afford further evidence of the banking up of abyssal water, and of water from the middepths, against the slope. The curves show that the salinity was rather higher in the middle of the profile than either farther west or farther east, instead of lower, like the temperature; but on the slope of the Bermudas salinity, like temperature, suggests a slight upwelling of abyssal water—i. e., it is only in the midlayers that salinity and temperature fail to agree. Below about

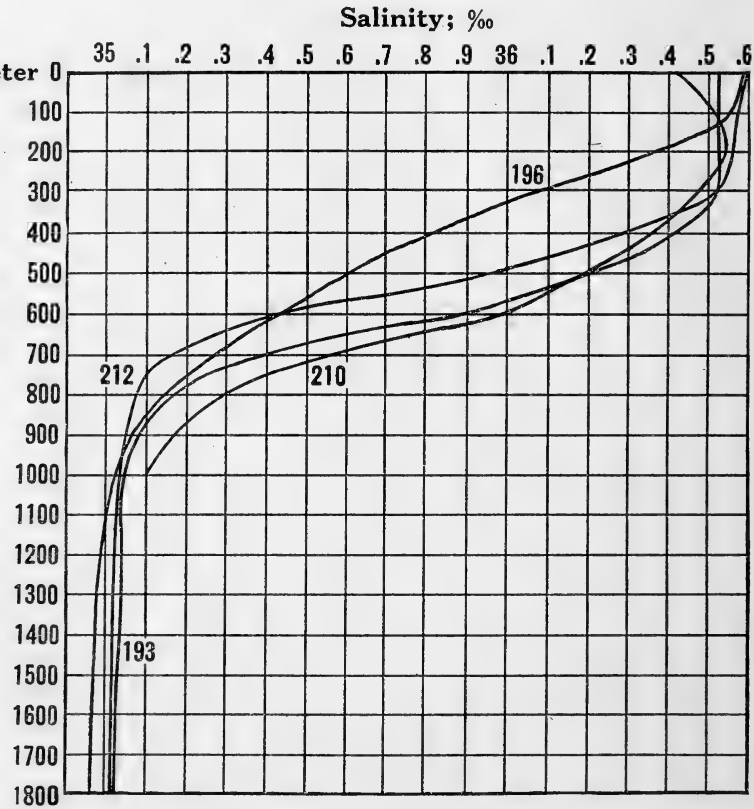

FIG. 10.—Salinity sections east of the Bahama Bank; stations 10193, 10210, 10212, and down to 1,800 meters in the northeast Providence Channel, station 10196.

1,800 meters abyssal water with practically uniform salinity (34.9°/₀₀) was encountered.

The upper layers of water were colder over the southern slope of the Bermuda Bank (station 10179, fig. 13) than over the northern (station 10177, fig. 11), the difference being greatest (3°) at 1,200 meters; but below 1,400 meters the northern slope was the coldest. Along the line running southwest from Bermuda (fig. 13) the surface layers grew gradually warmer toward the south, the curve for 15° dipping from 550 to 700 meters, while near the surface the temperature rose from about 18° to 20°, and the peculiar S-shaped curve for 20° suggests an active mixing of cool and warm surface water. In the deeps, below 700 meters, the curves reveal a pronounced upwelling of cold abyssal water at station 10181, and the salinity profile (fig. 14) along this line shows much the same thing, the surface layers down growing salter, from north to south, while in the deeper layers salinity, like temperature, curves rise at station 10181.

The temperature profile from Florida to a point 200 miles southwest of Bermuda (fig. 15) shows that water warmer than 20° was thickest near the Bahama Bank (about 200 meters). East of this the curve of 20° rises to 50 meters at station 10191, then dips, as a tongue, to

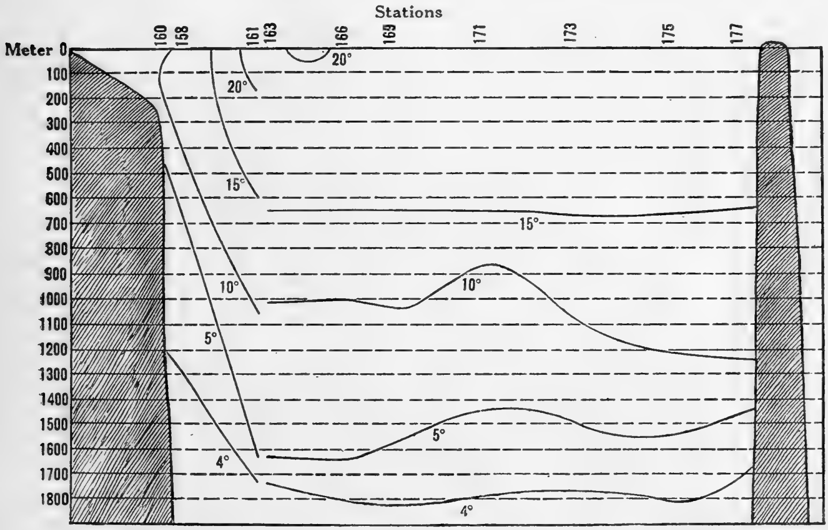

FIG. 11.—Temperature profile of the upper 1,800 meters from Chesapeake Bay to station 10161; and from a point 130 miles south of the latter to Bermuda.

150 meters at station 10189, where the surface was 19.6°. But 20° water is again seen at the eastern end of the profile. The curves for 15°, 10°, and 5° are roughly parallel with each other, showing a succession of cold and warm undulations, but, as a whole, dipping from west to east, the former from about 500 to about 700 meters, the latter from about 1,100 to about 1,600 meters. The most striking of these undulations is a well-developed cold band some 300 miles southwest of Bermuda (station 10185), and this is evidenced by an upswing of the curves down to 1,800 meters, as well as by lowered surface temperature. Immediately east of it, however, the water, as a whole, is warmer than anywhere else along the profile. The temperature then falls toward the west from station 10187 to station 10212; but there is a well-marked warm band over the 1,800-meter contour on

the slope of the Bahama Bank. The temperature sections along this line (fig. 5, 6) show that practically the entire cooling from the surface downward takes place in the upper 1,500 meters; and below about 1,800 meters the west-east dip is still evident. The profile illustrates sufficiently the contrast between the Antilles water on the one hand and the Florida current water on the other, for while the latter is even warmer than the former on the surface, water colder than 10° comes much nearer the surface in it, what we may call an entire oceanic section being compressed into a channel only some 700 meters deep, and the banking up of cold bottom water on the left-hand side is much more extreme in the Florida than in the Antilles current.

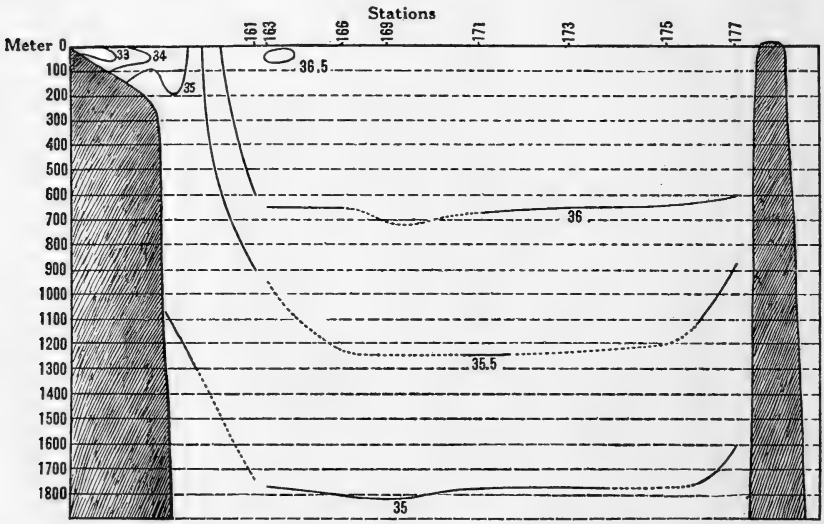

FIG. 12.—Salinity profile of the upper 1,800 meters, Chesapeake Bay to station 10161, and from a point 130 miles south of the latter to Bermuda.

Salinity (fig. 16) agrees very well with temperature along this profile down to 1,200 meters. Thus, the curve of 36°/₀₀ is almost exactly parallel with that of 15°; the curves of 35.5°/₀₀ and 35.3°/₀₀ roughly, though not exactly, parallel with 10° and 5° temperatures, respectively. Consequently, below 500 meters the two combined show a mass of warm water of high salinity south of Bermuda; a band of cool, comparatively fresh water at station 10185; next, a second warm salt mass about 300 miles southeast of Bermuda, followed by a general cooling and decline of salinity as far as the 1,800-meter contour on the slope, where there is a third well-marked warm salt band. Between the 500-meter level and the surface the general trend of the salinity curves is different, the saltest water as a whole lying northwest of the Bahama Bank, where there is a layer about 300 meters thick with salinity above 36.5°/₀₀. Farther east this strikingly saline layer is much thinner and it is twice interrupted (stations 10189 and 10185), though it once more appears near Bermuda. Over the northern end of the Bahama Bank the 36.5°/$_{oo}$ water is overlaid by fresher water, as described for the Jupiter Inlet profile across the Florida current (p. 32). Below 1,200 meters there is very little further decrease in salinity: At 1,800 meters it ranges from 34.96 to 35.01°/$_{oo}$ only, and judging from what is known of Atlantic bottom water (Murray and Hjort, 1912; Nansen, 1912), it is probably practically uniform below that depth. Though the curve of 35°/$_{oo}$ suggests a slight upwelling of this abyssal water in the center of the profile, the entire range of variation of

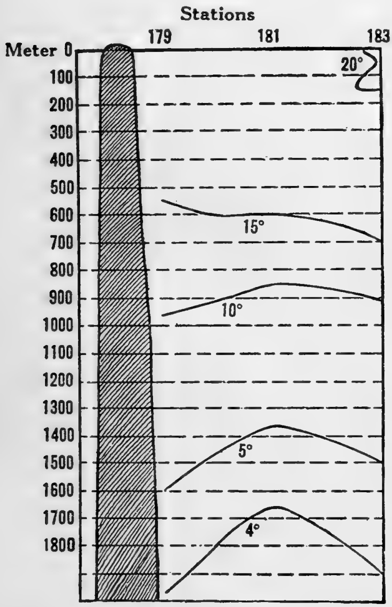

FIG. 13.—Temperature profile of the upper 1,800 meters, on a line running 200 miles southwest from Bermuda.

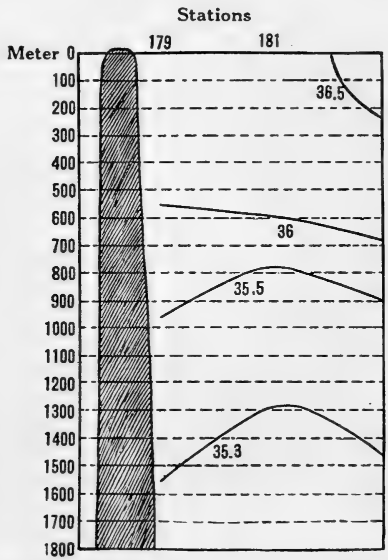

FIG. 14.—Salinity profile of the upper 1,800 meters, on a line running 200 miles southwest from Bermuda.

salinity below the 1,000-meter level is so small that it is doubtful whether this was really the case. Certainly, temperature suggests nothing of the kind but just the reverse.

The relationship of these profiles to one another may be illustrated further by charts of the temperatures and salinities at the 200, 600, 1,000, and 1,800 meter levels.

At 200 meters salinity was remarkably uniform, the extreme range, except for the cool, fresh water next the coast (station 10158, p. 45), being from 36.42°/$_{oo}$ to 36.55°/$_{oo}$ only. The temperature range (fig. 17) was also very small, 18.1° to 19.3° over most of the area. Next the coast off Chesapeake Bay it was much colder (11.2° at station 10158); but east of station 10161 the temperature at this level was nowhere below 18°. Off the mouth of the Straits of Florida and off the northeastern slope of the Bahama Bank (station 10210)

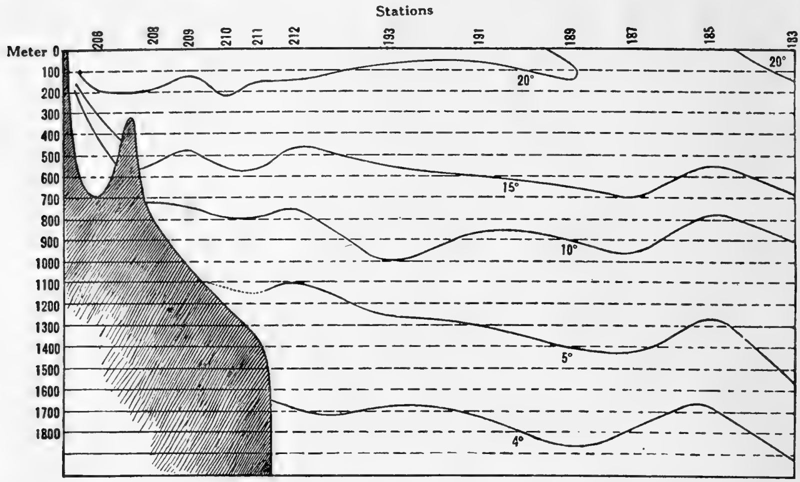

FIG. 15.—Temperature profile of the upper 1,800 meters, from Florida to a point 200 miles southwest of Bermuda.

the 200-meter temperature rose to 20°, and it was even warmer (22°) in the northeast Providence Channel (station 10196). The course of the curve of 19° is worth notice, since it shows a tonguelike extension

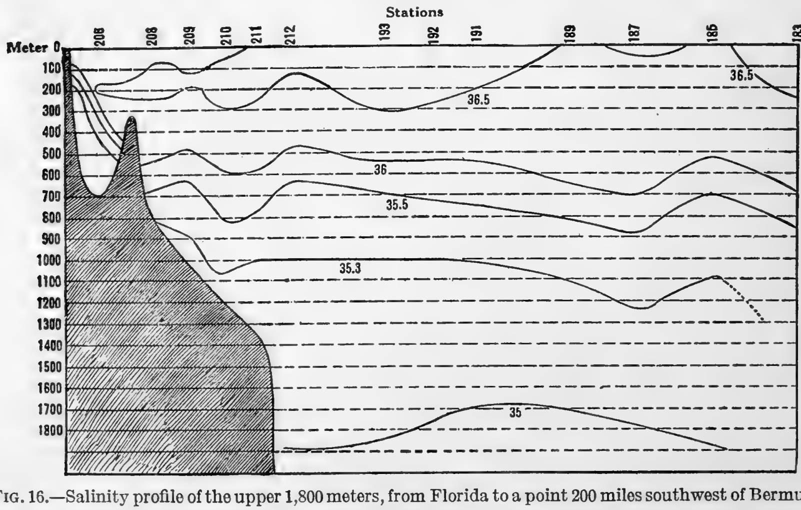

FIG. 16.—Salinity profile of the upper 1,800 meters, from Florida to a point 200 miles southwest of Bermuda.

of warm water parallel with the coast, recalling the surface (fig. 1). But this phenomenon was limited to the upper 300 to 400 meters, for at 600 meters (fig. 18) the water was warmest (16°) west of

Bermuda, over a roughly oval area with slightly colder (15°) water on the east, south, west, and, probably, on the north also. South of Bermuda the temperature was below 15°. And it was even colder (12°) off the Bahama Bank, falling to 10° in the northeast Providence Channel, and probably all along the continental slope, with a temperature of only about 5° off Chesapeake Bay at this level. The extension of a tongue of 12° northward from the Bahama Bank suggests that part of the cold water, which is banked up against the latter, is drawn here into the general northerly drift of the Antilles

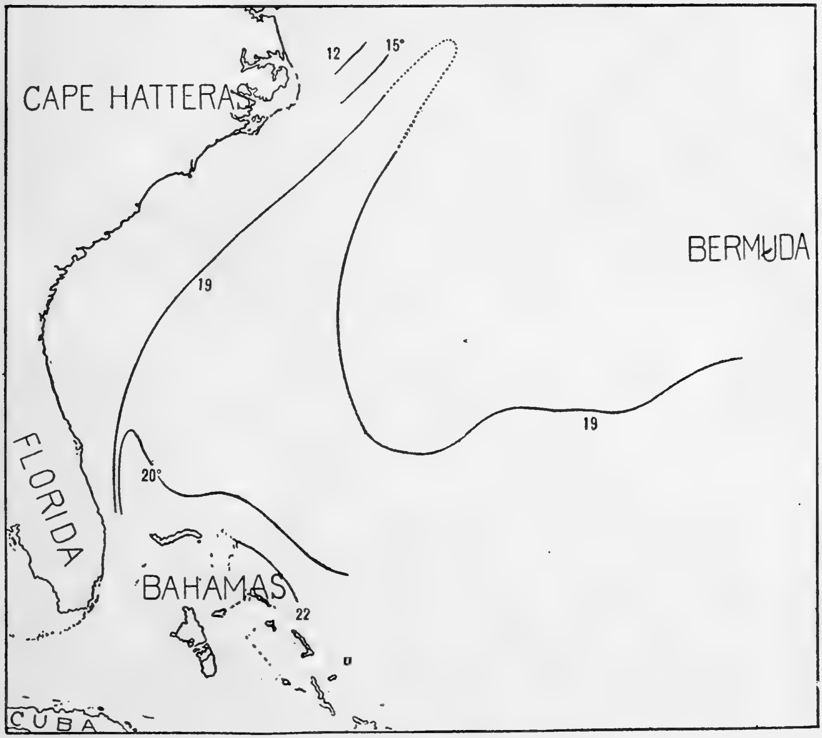

FIG. 17.—Temperatures at 200 meters.

current; but apparently the cold water at station 10185 was the result of local upwelling, not of a cold band.

The distribution of salinities at 600 meters (fig. 19) suggests, although it does not parallel, the temperature, the water being saltest (over 36.1°/₀₀) west of Bermuda, where the curve of 36°/₀₀ incloses a roughly oval area, which was probably limited by water of lower salinity on the north, as it certainly was on the east, south, and west. The low salinity of station 10185 is as clearly a local phenomenon, as is its low temperature. Over the southwestern part of the area in general the salinity was very uniform (36–36.08°/₀₀); but north of the Bahama Bank and along the continental shelf the water was much fresher, its salinity falling to about 35.5‰ off the northeast slope of the bank, as far as station 10212, and in the Providence Channel, to 34.9‰ in the exit of the Straits of Florida (station 10206), and to about 35.1‰ off Chesapeake Bay. Thus, the low temperature and salinity which characterize the surface waters west of Bermuda (p. 6, 7) were limited to a shallow zone, this being the warmest and saltest area at the 600-meter level. Similarly the very high surface temperature at the mouth of the

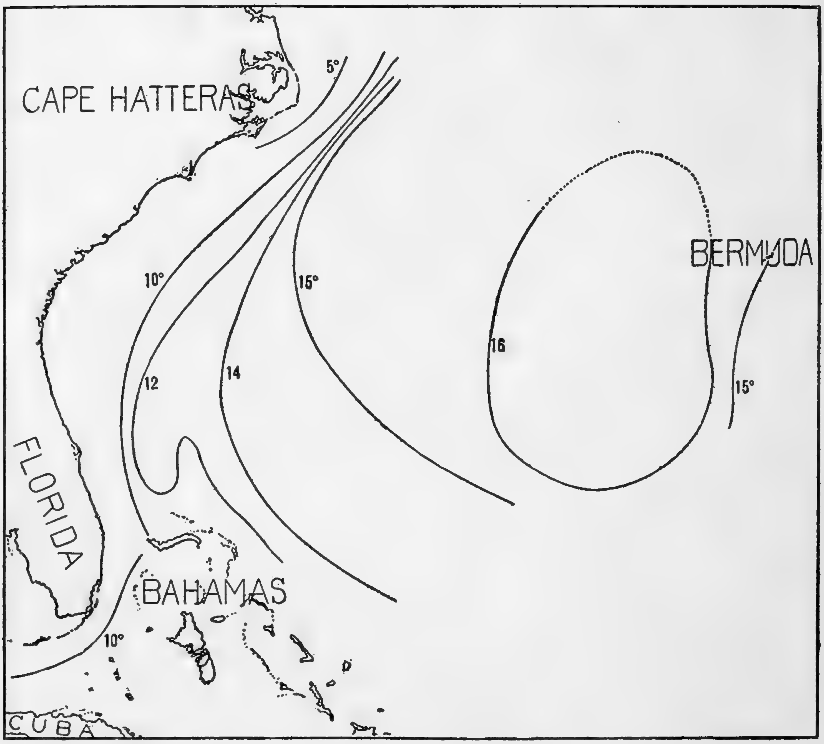

FIG. 18.—Temperatures at 600 meters.

Straits of Florida and northeast of the Bahamas in general was equally superficial, cold water rising nearer to the surface there than over the oceanic basin.

At 1,000 meters conditions are puzzling. It is clear that the temperature at this level was highest (12°–13°) northwest of Bermuda, and that most of the area studied was about 10°, with cooler water near the coast—i. e., that the general distribution of temperature was essentially similar to that of the 600-meter level. But the low temperatures (about 7°) at stations 10181, 10183, 10185, and 10171, suggest a tongue of cold water, extending from southeast to northwest, right across the area traversed by the *Bache*, which has no counterpart at the higher level. Its outline forbids the assumption that it can be northern water, unless in the form of an upwelling. However, the existence of such a tongue depends on the temperature reading at station 10171, and as this is not accompanied by correspondingly low salinity, but the contrary, it is natural to wonder whether it is correct. Discarding this one reading, the warm (10°) water would hardly be indented on the southeast (fig. 20), and the temperature curves would agree much more closely with the salinities. The

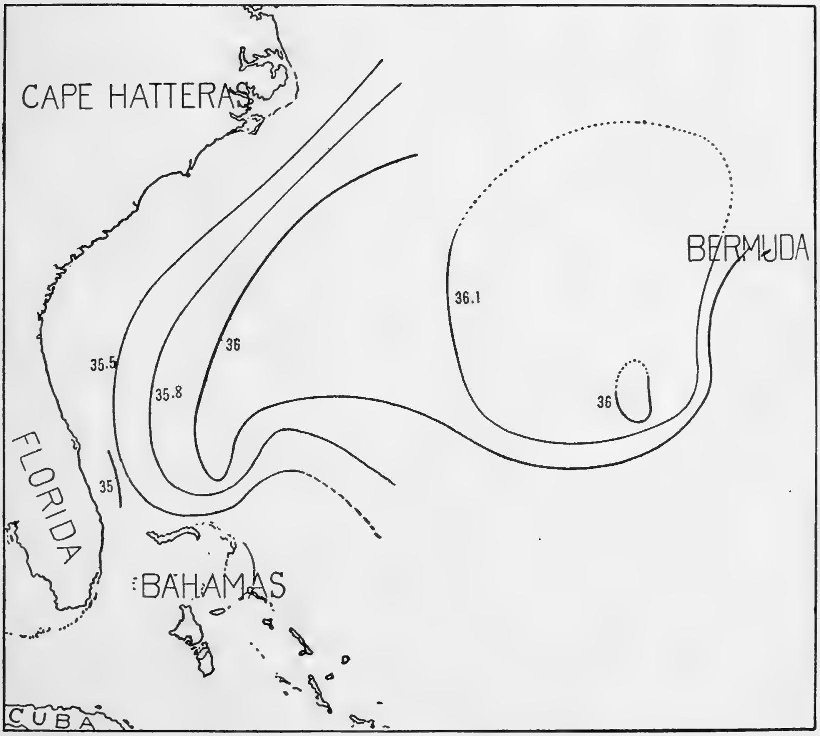

Fig. 19.—Salinity at 600 meters.

lowest temperatures at this level were off Cape Hatteras (4°–5°) and off the Bahama Bank, and it is probable, though not certain, that there was a continuous belt of cold water all along the continental slope. Salinity (fig. 21) like temperature at 1,000 meters was highest northwest and west of Bermuda, with a similar slight indentation by fresher water on the southeast. Although the salinity, unlike the temperature, is practically uniform over a considerable area east and northeast of the Bahama Bank—i. e., affords no evidence of upwelling on the slope—this apparent difference is not essential, because the comparative uniformity of salinity below 1,000 meters makes it a far less obvious index to upwelling than temperature at this or greater depths. At 1,800 meters the temperature was very nearly uniform, the extreme range being only from 3.5° to 4.2°, with water as warm as 4° for approximately 400 miles west of Bermuda. At this level the extreme range of salinity was only 0.07°/₀₀ (34.94–35.01°/₀₀), water of 35°/₀₀ occupying an elipse between Bermuda and the Bahamas, apparently surrounded by slightly fresher water—i. e., roughly corresponding to the area of highest temperature at this level. Thus, the effect of the warm salt water of the Florida and

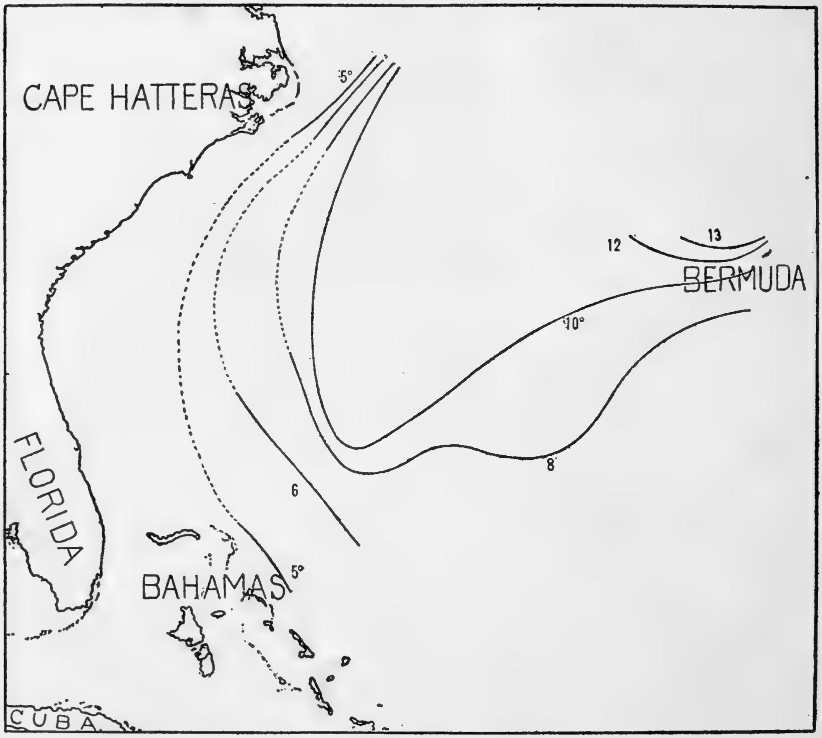

FIG. 20.—Temperature at 1,000 meters.

Antilles currents, so noticeable on the surface, is hardly to be traced below 600 meters, by either salinity or temperature. On the contrary, the cold, comparatively fresh water of the deeps rises nearer to the surface under them than in the region west of Bermuda, and apparently this is also the case south and east of Bermuda. Thus we have, west of Bermuda, a mass of water distinguished by high temperature and salinity, from about 200 down to 1,800 meters.

There is, of course, nothing novel in the observation that the water, as a whole, is warmer west of Bermuda than farther south or east—i. e., that the cold abyss water is farther from the surface. Indeed, the general approach of the water of the abyss toward the surface, from about latitude 30° toward the Equator, is one of the most essential features of oceanic temperature and one of the most significant in its bearing on the general system of oceanic circulation.[a]

It is interesting that while the 600-meter temperatures of the *Bache* agree very well with earlier records, the warmest water west and northwest of Bermuda being 16.3°–16.5°, as against 16.8° as given by Schott (1902), at 1,000 meters the *Bache* records are notably warmer, 13° as against 8.2°, according to Schott (1902, 1912)—that is to say, the

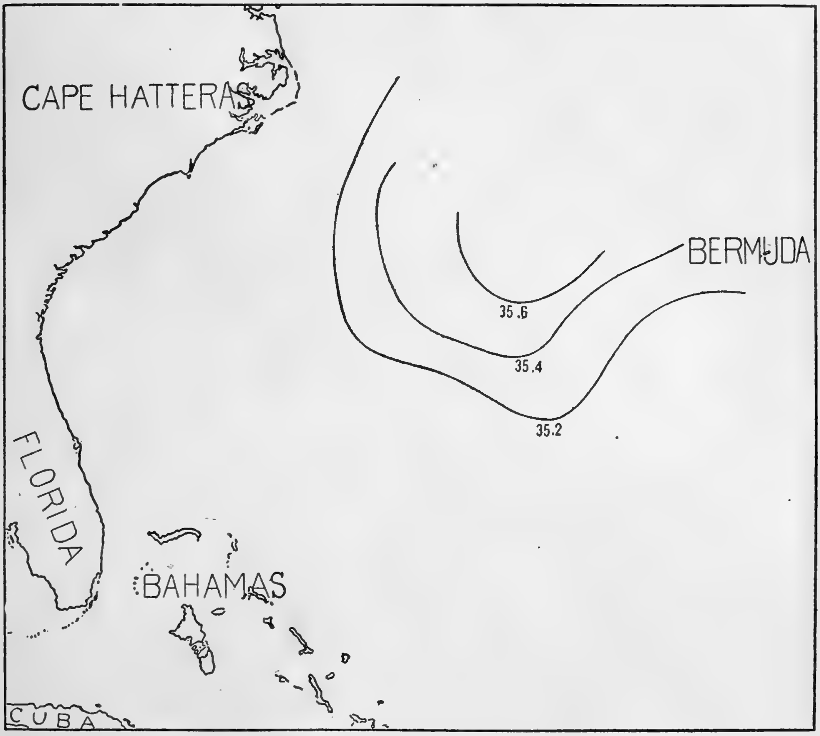

FIG. 21.—Salinity at 1,000 meters.

abyss water was farther from the surface—and even at 600 meters the area of 6° water extended farther to the south (to about 28° north latitude) than it is represented by Schott (about 31° north latitude), though hardly as far to the westward. Otherwise, the *Bache* and *Valdivia* charts agree very well for this level. Even at 1,000 meters, the geographic location of the absolute maximum is very nearly the same in Schott's chart as in our own. In short, the work of the *Bache* corroborates in general the earlier temperature records; but the salinities are a distinct addition to oceanography, there

[a] For an excellent account of this phenomenon, see Schott (1912), p. 130.

being practically no previous records for the middepths in this region. The discovery that the general distribution of salinity is the same as that of temperature—i. e., highest west of Bermuda (except on the immediate surface)—is a further corroboration of the upwelling of abyssal water toward the Equator.

THE STRAITS OF FLORIDA.

The Straits of Florida are historic grounds for oceanographic study, thanks to the temperatures taken by the *Blake* (Agassiz, 1888) and to the numerous current measurements made by the United States Coast and Geodetic Survey, especially by Capt. Pillsbury (1886, 1887, 1889). However, it remained for the *Bache* to obtain satisfactory series of

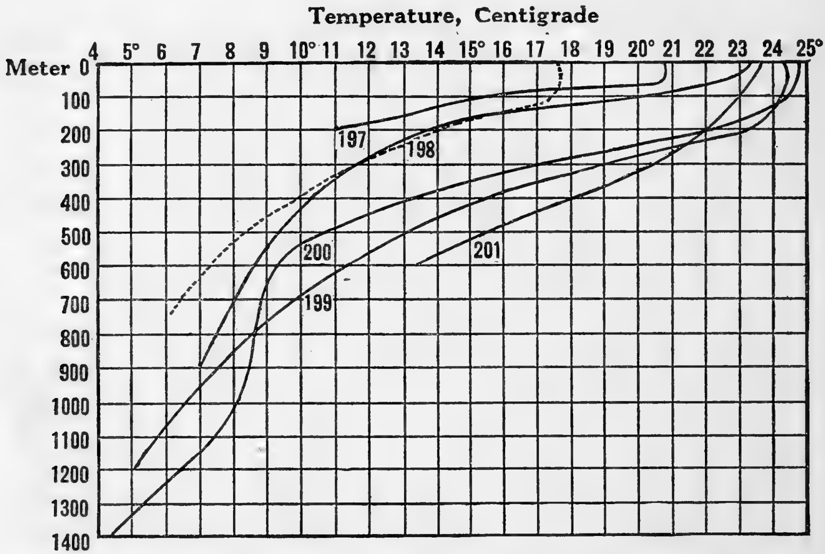

FIG. 22.—Temperature sections on the line Key West-Habana; stations 10197, 10198, 10199, 10200, 10201; and off Pensacola, Fla., March 13, 1885 (......, *Albatross*).

salinities, simultaneous with temperatures. Three profiles were drawn across the Straits—one from Key West to Habana, one from Cape Florida to Gun Cay (coinciding with the *Blake* and with Pillsbury's profiles), and the third from off Jupiter Inlet to the northern end of the Little Bahama Bank.

The *Bache* found a general rise in surface temperature, from north to south, along the whole length of the channel, the water being warmest (24.70°) approximately 20 miles from Habana—i. e., in the position of the axis of the Florida current at low declination of the moon. The surface was cooler immediately off Key West than anywhere else in the Straits (station 10197, 20.78°) with a slight but progressive warming along the Florida coast from southwest to east and north.

Water warmer than 24° was confined to the southern and western part of the channel, and the water in the Old Bahama Channel was probably as warm as 24°, while the surface was fractionally cooler along the western face of the Bahama Bank. At the northern end of the channel the surface temperature was 23.6°–23.7°, and it was considerably cooler east of the Bahama Bank, as pointed out (p. 6). Thus, the inequalities in surface temperature are gradually dissipated from west to east and north, the temperature range diminishing from 4° off Habana to practically zero off Jupiter Inlet. As a whole, the Straits were considerably warmer on the surface than the Atlantic water east of the Bahama Bank.

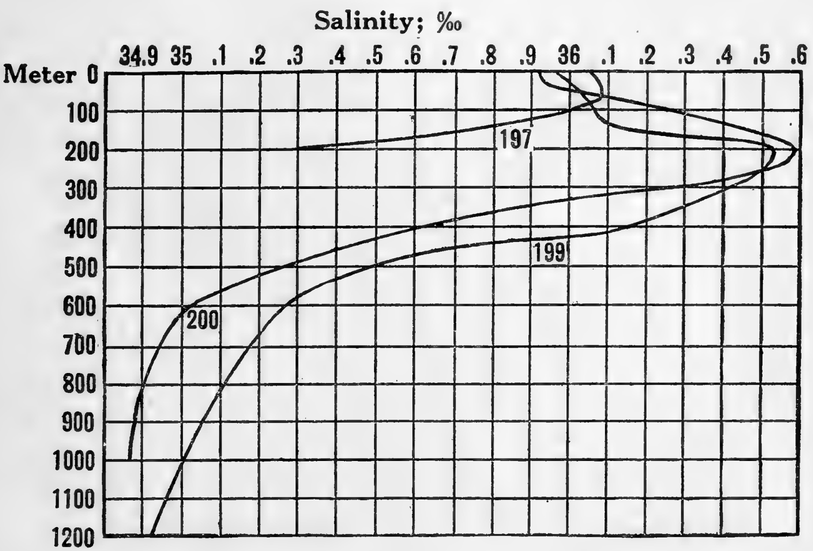

Fig. 23.—Salinity sections on the line Key West-Habana; stations 10197, 10199, 10200.

The surface salinity was much more uniform than the surface temperature, the extreme range over the whole length of the channel being about 0.27‰ only (35.9° to 36.17‰).

The serial observations on the Key West-Habana line (fig. 22, 23) show that off Key West the water cooled from nearly 21° on the surface to 11° at 200 meters; 20 miles farther south from 23° to 14°; in the center of the channel only from 23.5° to 22° in the same depth. Below that depth the curves of the temperature sections on this line approach each other, the temperature range at 900 meters being only 1.5° (7°–8.5°). The warmest station was in the center of the Strait (station 10201). Unfortunately, serial water samples were taken at only three of these five stations (none at station 10201, perhaps the most interesting of all). However, they show that the salinity was lowest immediately off Key West (station 10197), and that in the southern half of the channel (stations 10199 and 10200) the saltest water (about 36.5°/₀₀) was at 200 meters, with 36°/₀₀ water on the surface above it. Below the 200-meter level there was a rapid vertical decline of salinity to about 35–35.2°/₀₀ at 600 meters, followed by a much slower decrease, to about 34.9°/₀₀ at 1,100–1,200 meters. The temperature and salinity profiles (fig. 24, 25) constructed from these sections show that water colder than 10°, and with salinity lower than 35°/₀₀, was banked up against the Florida slope to within 200–300 meters of the surface. On the Cuban side of the profile water of 35°/₀₀ was met only below about 900 meters (10° water at 700 meters). The coldest water of all (4°–5°) lay on the bottom off Habana below 1,300 meters, and water equally cold may have filled the trough below this depth, but

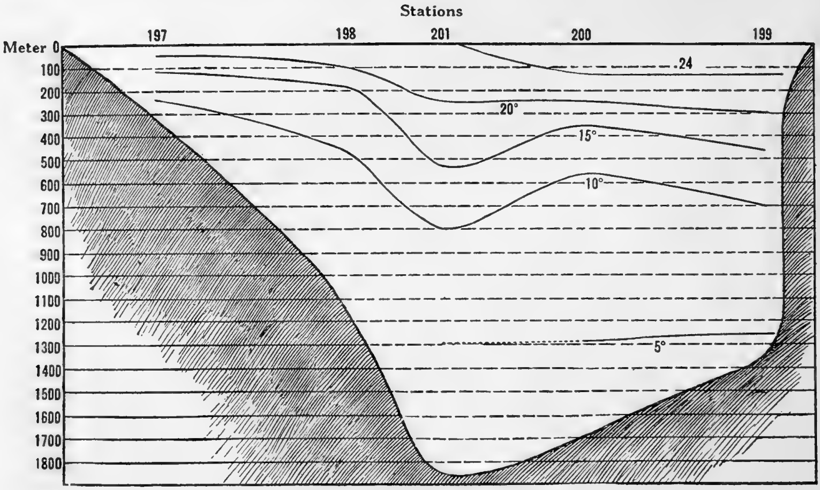

FIG. 24.—Temperature profile, Key West–Habana.

we have no records from this or greater depths on the north side. Perhaps the most striking feature of the profile apart from the cool fresh water off Key West is the band of warm water at 100–800 meters in the center of the channel outlined by the curves for temperatures between 10° and 20°. In the middepths this band was even warmer than the water next to the Cuban coast; but the surface water was warmest on the Cuban side where there was a surface layer about 100 meters thick of 24°–25°.

Unfortunately, the salinity profile is not complete, there being no salinities for the middepths at stations 10198 or 10201; hence it is a question whether the warm band just mentioned was characterized by high salinity as well as by high temperature. There is nothing in the data from the other stations along this line to forbid such an assumption. The range of surface salinity was only about

0.17°/₀₀ (from 35.93 to 36.1°/₀₀), the surface being freshest on the Cuban side, above the saltest water (36.5°/₀₀), as just noted.

Apart from a possible salt tongue in the center of the channel, the salinity curves as a whole dip from north to south, and it is worth

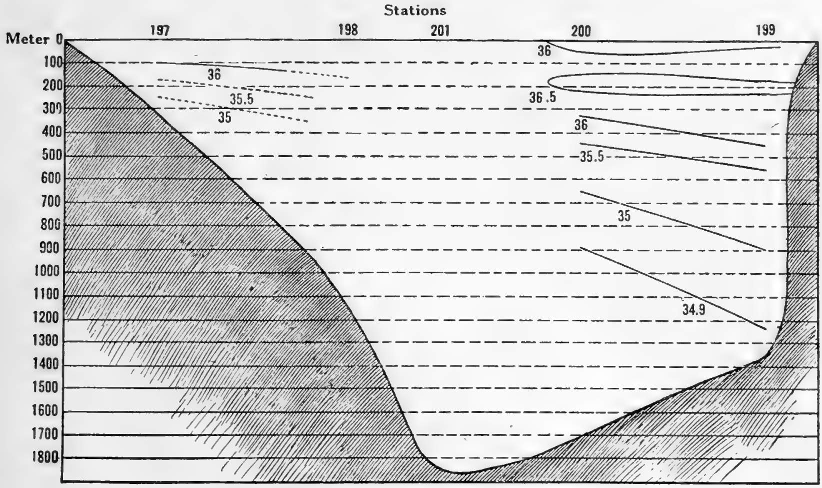

FIG. 25.—Salinity profile, Key West-Habana.

noting that the same vertical range of salinity (36 to 35°/₀₀) which occupies 900 meters at the southern end was condensed into 250 meters at the northern end of the profile.

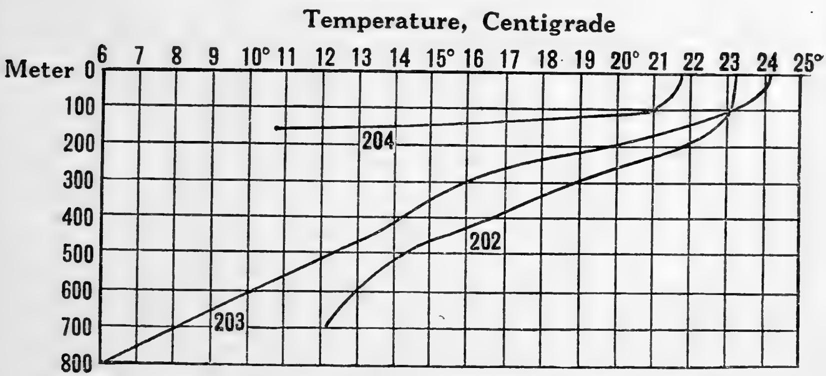

FIG. 26.—Temperature sections on the Gun Cay-Cape Florida line; stations 10202, 10203, 10204.

Between Cape Florida and Gun Cay the channel is only about 900 meters deep and 60 miles wide. Nevertheless, we find as great a range of salinity (fig. 27) and almost as great a range of temperature (fig. 26) as in the Key West-Habana profile. As before, the water was coldest and freshest next to Florida, warmest and saltest off the Bahama Bank; and the two eastern stations are saltest (36.5°/₀₀) at 200 meters, below which level there is a rapid decrease of salinity to 34.85‰ at 800 meters in the center of the channel, and to 35.5‰ at 700 meters off Gun Cay.

At all three stations along this line the vertical cooling was rapid, the temperature dropping off Cape Florida from 21° to 10.5° in a

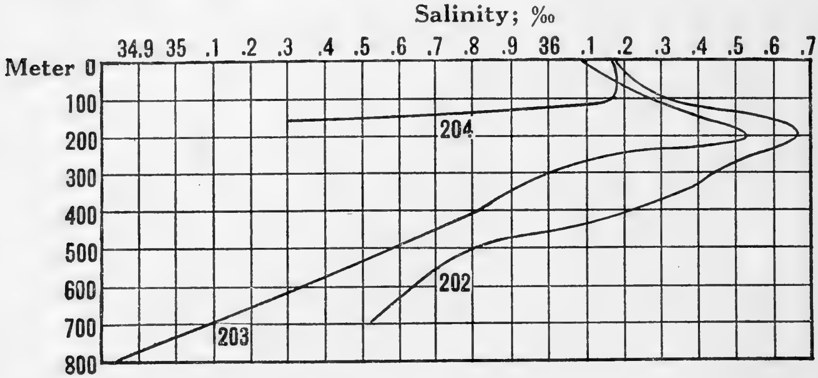

FIG. 27.—Salinity sections on the Gun Cay-Cape Florida line; stations 10202, 10203, 10204.

distance of 50 meters; from 24° on the surface to 6° at 800 meters in the center of the channel; from 23° to 12° in 700 meters off Gun Cay. The temperature profile (fig. 28) shows no trace of the warm tongue so conspicuous between Key West and Habana, and the warmest water (24°–25°) was on the surface in the center of the

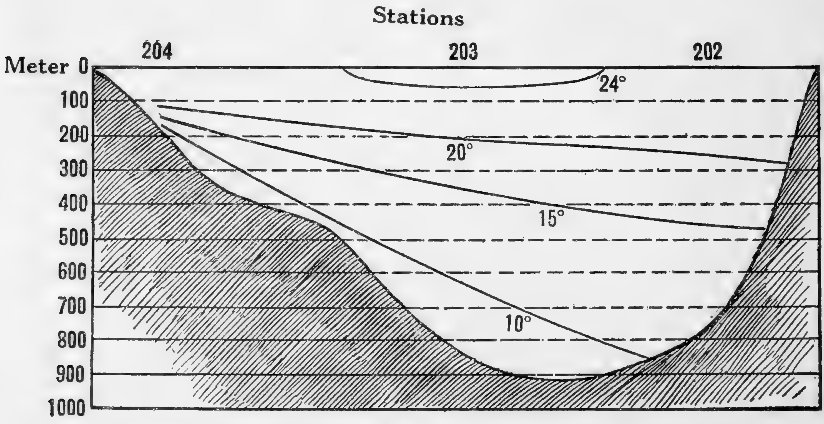

FIG. 28.—Temperature profile across the Straits of Florida, Gun Cay-Cape Florida.

channel, instead of on the Bahaman side, besides being fractionally cooler than the highest surface temperatures off Habana. The banking up of water colder than 10° and fresher than 35‰ against Florida is even more pronounced than in the preceding profile, water with these characteristics rising to within about 175 meters off Cape Florida; to about 250 meters off Key West. The same lenticular mass of 36.5°/₀₀ water (fig. 29) is to be seen on the Bahaman side and at the same level (200 meters), as off Cuba in the Key West-Habana profile. As in the latter, the surface is freshest where warmest, though this is now in the center of the Strait instead of on the Bahaman side. The whole range of surface salinity is only about 0.1°/₀₀. The curves for temperature colder than 20°, and salinities lower than 36°/₀₀, dip regularly from west to east, the curves for 36°/₀₀ and 15° coinciding almost exactly with each other, and the slope growing progressively steeper with decrease of temperature and salinity. The saltest and coldest water was in the deepest part of the channel, 34.85°/₀₀ and 6.16° at 800 meters.

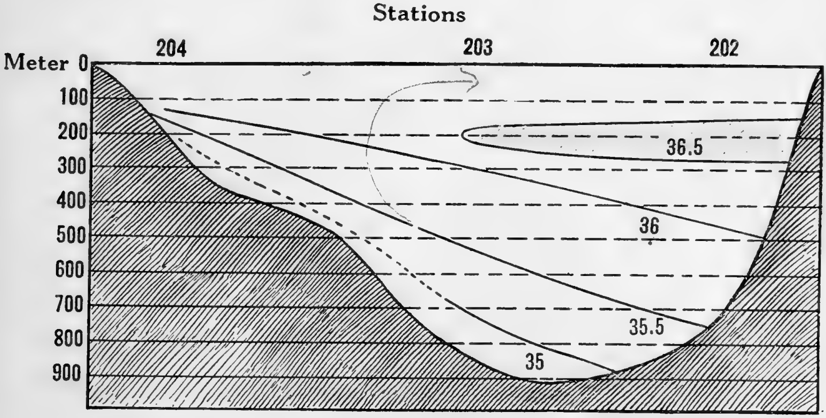

FIG. 29.—Salinity profile across the Straits of Florida, Gun Cay to Cape Florida.

Comparison between these two profiles shows that the subsurface temperatures between Cape Florida and the Bahama Bank agree very closely with those of the northern half of the Key West-Habana profile, the curve for 20° dipping from 25 or 30 meters near Florida to about 250–275, the curve for 15° to about 500 meters in both, but below 500 meters the Cape Florida profile is considerably the colder of the two, depth for depth, its 800-meter temperature being about the same as at the 1,200-meter temperature between Key West and Habana. There was probably a similar difference in salinity, though owing to the lack of data at stations 10198 and 10201 complete comparison is not possible.

We find the same general type of temperature and salinity sections (fig. 30, 31) along the Jupiter Inlet-Bahama Bank line, the water saltest at 200 meters, warmest on the surface, with the same general rise in temperature and salinity from west to east. The total range of both is as great as before, but the depth of the channel having decreased to only 700 meters, the vertical increase is even more rapid than on the Cape Florida line.

In the profiles (fig. 32, 33) the curves for 15° and 10° temperatures and for salinities of 36‰ and less dip from west to east, water of 10° and 35‰ rising to within about 200 meters of the surface off

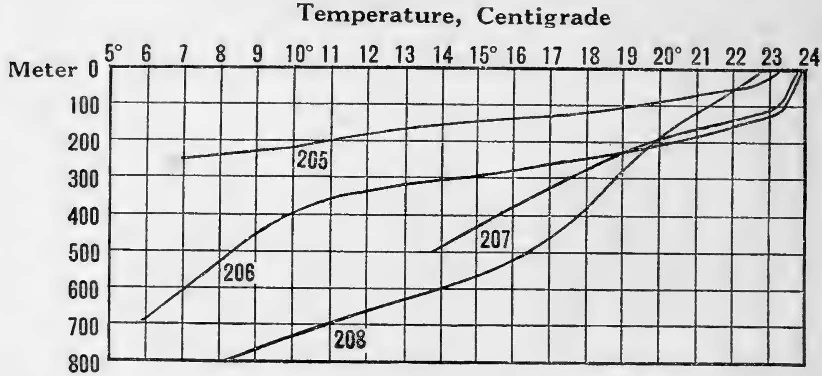

FIG. 30.—Temperature sections between Jupiter Inlet and the Bahama Bank, and east of the latter; stations 10205, 10206, 10207, 10208.

Jupiter Inlet; and as was the case off Cape Florida, the curves for 15° and 36‰ coincide with each other, but the curve for 20° temperature, which likewise dips near Florida, runs practically horizontal from the center of the channel eastward across the Bahama Bank. The mass of 36.5‰ water once more appears at 200 meters;

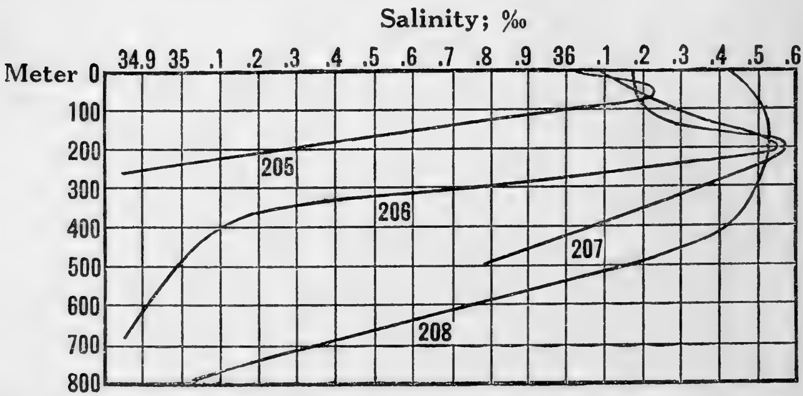

FIG. 31.—Salinity sections between Jupiter Inlet and the Bahama Bank, and east of the latter; stations 10205, 10206, 10207, 10208.

but instead of being limited on the east by a coast line, as was the case in the preceding profiles, it now extends across the northern end of the Bahama Bank, to join the 36.5‰ surface water farther east (fig. 16). There is no surface water as warm as 24° in this profile; but the difference between the warmest readings in it and the preceding profile is only fractional, while the surface was more uniform, and the mean surface temperature was fractionally higher (23.7°) along the Jupiter Inlet than the Cape Florida line (23.04°). In the bottom of the channel the water was of practically the same temperature (5.7°) and salinity (34.85°/₀₀) as between Cape Florida and Gun Cay, 100 meters deeper.

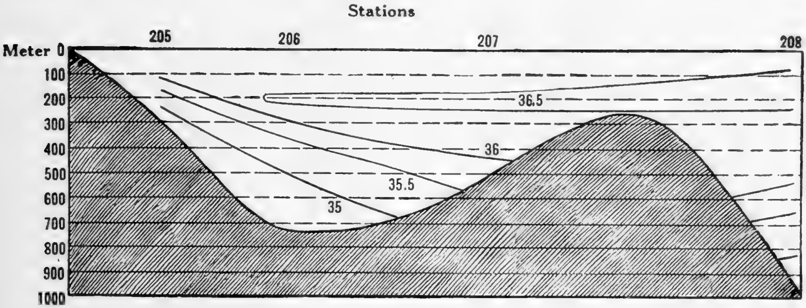

FIG. 32.—Temperature profile running east from Jupiter Inlet, across the northern end of the Bahama Bank.

The vertical condensation of salinity and temperature, and the general rise of cold fresh bottom water toward the surface from off Habana to the northern entrance of the channel is illustrated by an artificial profile lengthwise of the axis of the channel (fig. 34), reconstructed from the preceding transverse profiles. Several features deserve mention. The very warm surface water has been sufficiently emphasized. Beneath it lies a band of salter, cooler water (36.5°/₀₀

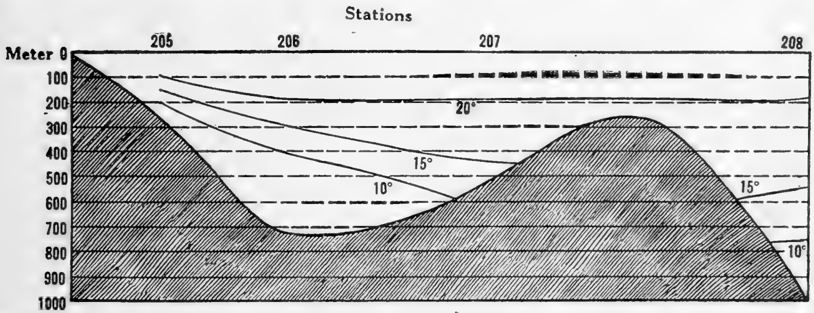

FIG. 33.—Salinity profile, running east from Jupiter Inlet, across the northern end of the Bahama Bank.

and 20°) extending the whole length of the profile, and continuous in both salinity and temperature with the surface water east of the Bahama Bank (p. 19, fig. 15, 16). Whether it is also continuous with the surface water of the Gulf of Mexico is not certain. Finally, at the northern end of the profile the rise of water of 6°–10° temperature and 34.8–35°/₀₀ salinity toward the surface is very evident; but water colder than 5° does not rise up the slope above the 1,100-meter level. Water of this temperature was also encountered at about this same level east of the Bahamas and also in the Providence Channel (station 10196).

The distribution of temperature and salinity may be further illustrated by charts of the 200, 400, and 600 meter levels.

At 200 meters (fig. 35) there was a general rise of temperature from north and west to south and east from about 10° close to the coast of Florida to 23° off Habana and 21.8° off Gun Cay. Opposite Jupiter Inlet, however, the warmest water (20.13°) was in the center of the channel at this level, with a fractionally lower reading (19.93°) off the northern end of the Bahama Bank. The range of salinity at

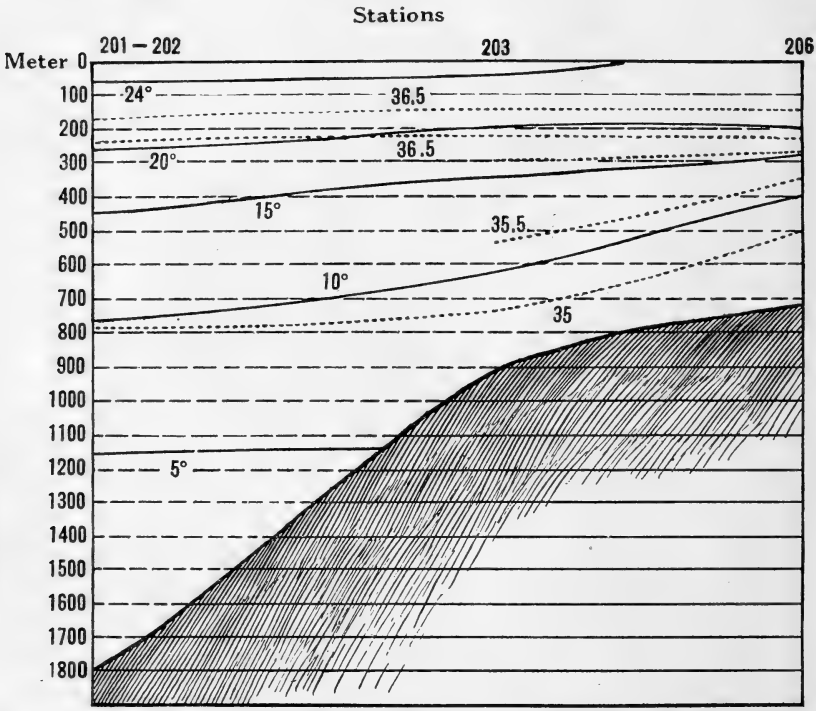

FIG. 34.—Profile of salinity (........), and temperature (_______), lengthwise of the Straits of Florida. Horizontal scale.

this level was only 1.37‰ (35.3 to 36.67‰) with the water freshest close to the coast of Florida, while the salinity of the southern and eastern half of the channel ranged from 36.5 to 36.67‰ (fig. 36).

At 400 meters (fig. 37) there was a general west to east warming in the northern half of the channel from about 9° near Florida to 16° near the Bahama Bank; but off Key West this was complicated by the warm tongue of 17° in the center of the channel, already described for the Key West-Habana profile. At this level the range of salinity (fig. 38) was from 35.1‰ (station 10206) to 36.2‰; lowest close to the coast of Florida, highest on the south and east side of the channel, the curves for 35.5 and 36°/₀₀ suggesting, although they do not precisely reproduce, the curves for 10° and 15° temperatures, respectively. The lack of data from the mid-depths at station 10201 leaves the possibility open that there may have been a tongue of still salter water at the west end of the channel, to correspond with the tongue of high temperature there.

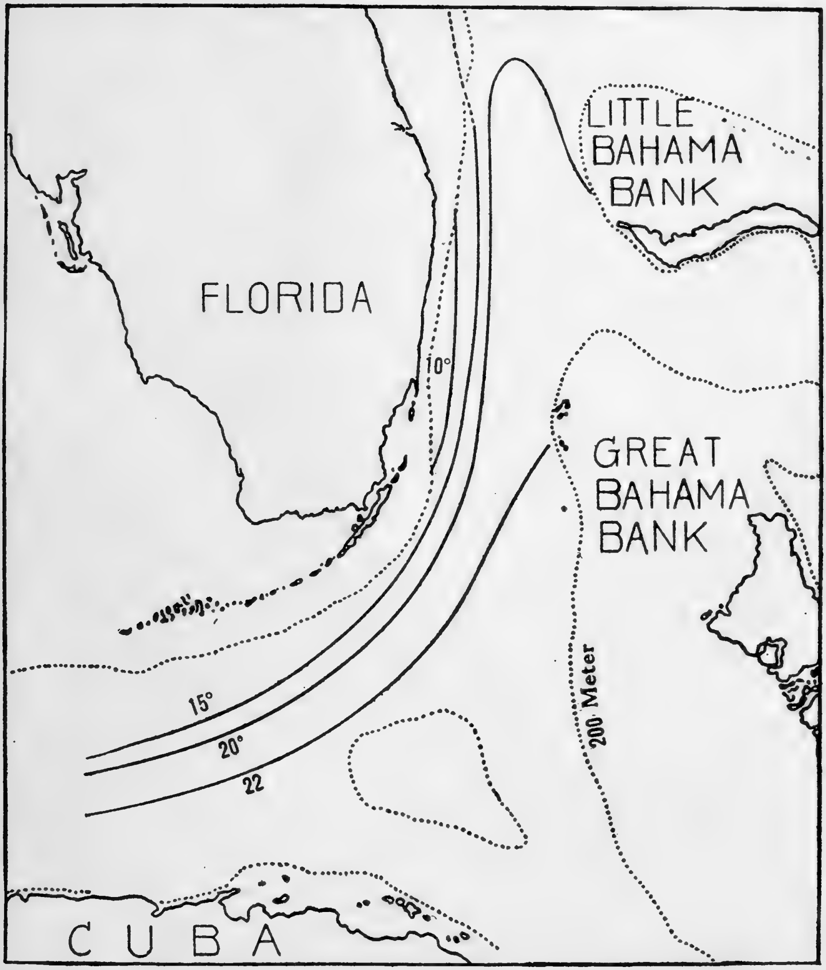

FIG. 35.—Temperature in the Straits of Florida at 200 meters, March, 1914.

At 600 meters, however (fig. 39), the warm water at station 10201 has lost its tonguelike character, being continuous with the general temperature (12°–13°) of the southeastern and eastern parts of the Straits. At this level the water was 7°–10° along the Florida side of the channel, and there was a second cold area off Habana (9°–10°), apparently a tongue from the west.

At 800 meters the distribution of temperature was much the same, coldest off Florida, and again off Habana, warmest in the center of the channel between Key West and Habana, and on the east side of the Straits, but the absolute value everywhere 1°–3° lower. Below 800 meters there was a general rise in temperature from north and west to south and east.

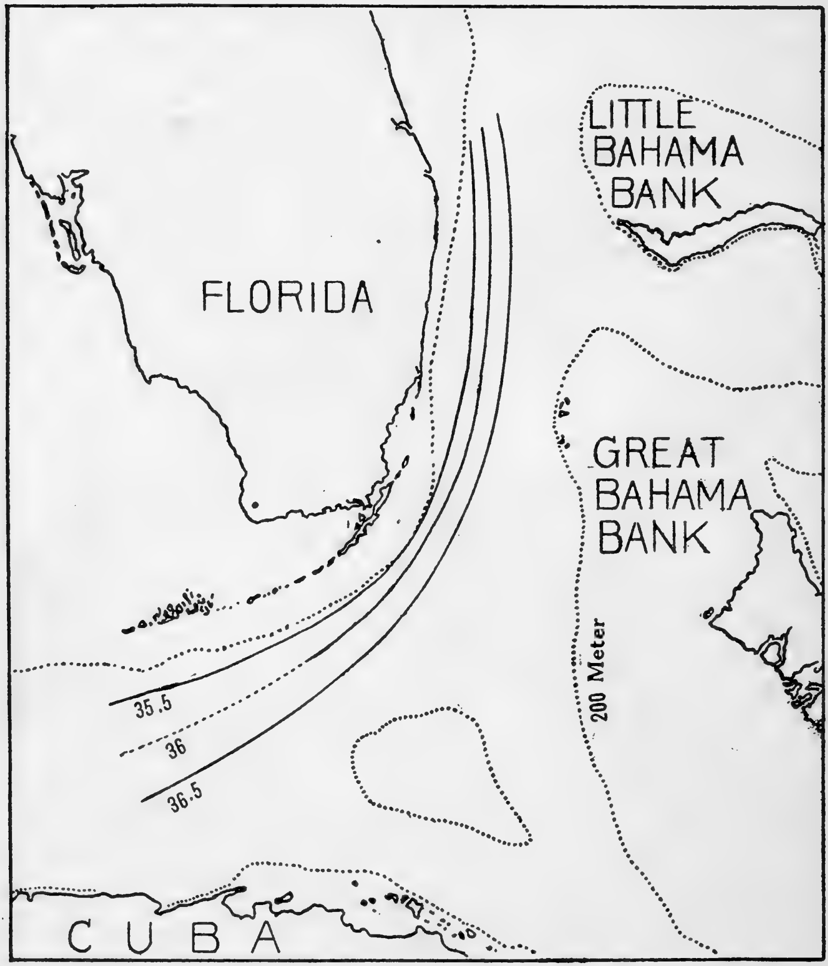

FIG. 36.—Salinity in the Straits of Florida at 200 meters, March, 1914.

Owing to the insufficiency of the records on the Key West-Habana line, it is not possible to plot the 600-meter salinity. In the northern half of the channel it ranged from about 34.9‰ off Florida to 35.6‰ off the Bahama Bank, the curve for 35‰ running, roughly, north and south. Judging from stations 10200 and 10199, where the salinity, respectively, was 35 and 35.27‰, and from station 10197, where it was 35.3°/₀₀ at 200 meters, there was probably a general rise, north to south, from below 35°/₀₀ to about 35.3°/₀₀ at 600 meters, at the west end of the Straits as well. This rise in salinity, from the Floridan to the Cuban and Bahaman side of the channel, is still traceable at 800 meters, where the salinity rose from 34.85–34.9°/₀₀ at stations 10200 and 10203 to 35.1°/₀₀ off Habana and 35.4°/₀₀ off Gun Cay.

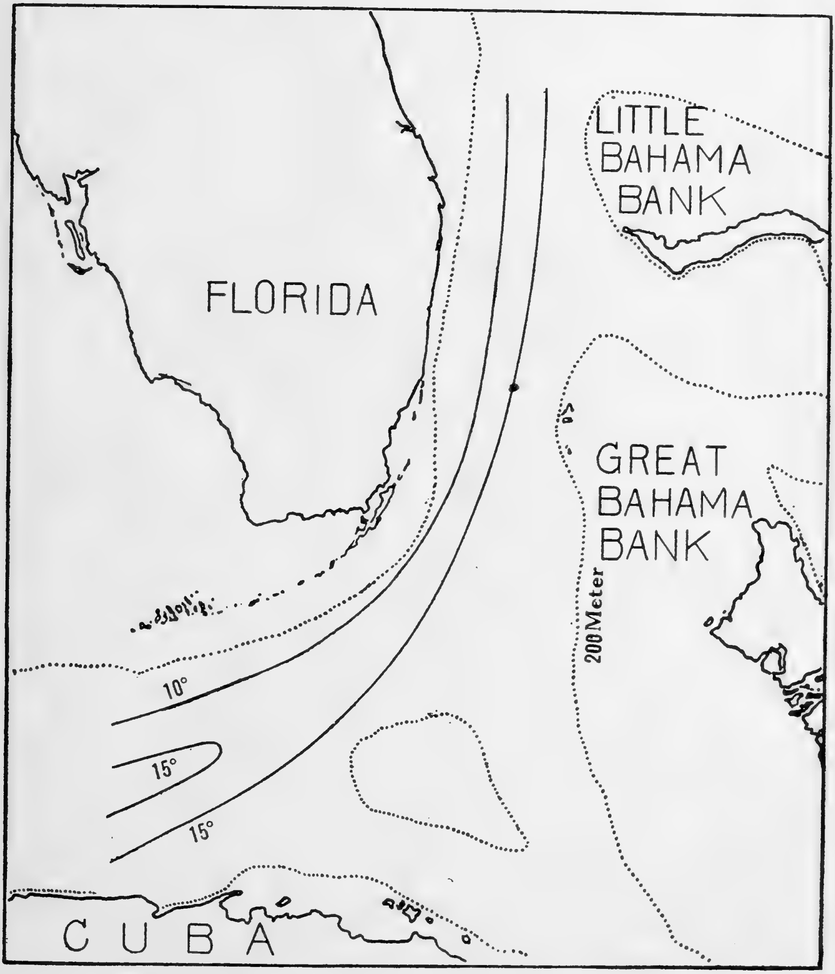

FIG. 37.—Temperature at 400 meters in the Straits of Florida, March, 1914.

The future must show whether the salinities outlined above are normal for the Straits, there being no reliable data for comparison; neither, for that matter, are the subsurface salinities known for any part of the Gulf of Mexico, the various hydrometer readings which have been taken there being too high (Krümmel, 1907, p. 357), nor for the water immediately north of the Bahamas. But the *Blake* temperature series taken in 1878 between the Tortugas and Cuba, and on the Cape Florida-Gun Cay line, reveal the same general dip of the temperature curves from north and west to south and east, and the same banking up of cold water against Florida that characterize the profiles run by the *Bache*.

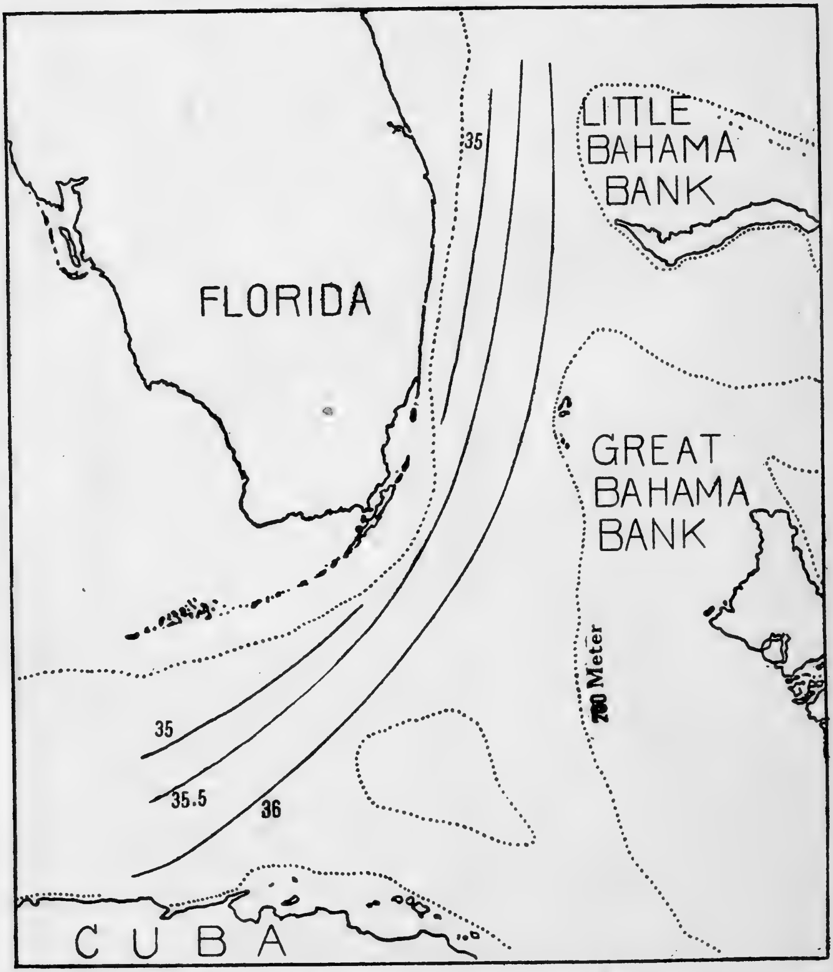

FIG. 38.—Salinity at 400 meters in the Straits of Florida, March, 1914.

At the western end of the Straits the temperatures for the two years agree very closely off Cuba (fig. 40) and on the Florida side (fig. 41), except that the immediate surface was warmer in May, 1878, than in March, 1914, as might have been expected from the difference in season. Otherwise the only notable deviation in the curves is that the 1,800-meter temperature was 5° higher in 1878 than in 1914, the water between 700 and 1,300 meters 1°–1.5° colder; and in the center of the channel (fig. 42) the water was considerably colder in the middepths in 1878, the warm band so notable in the *Bache* profile being absent. Consequently, the temperature curves in the *Blake* profile (Agassiz, 1888, p. 231, fig. 157) dip more regularly from north to south.

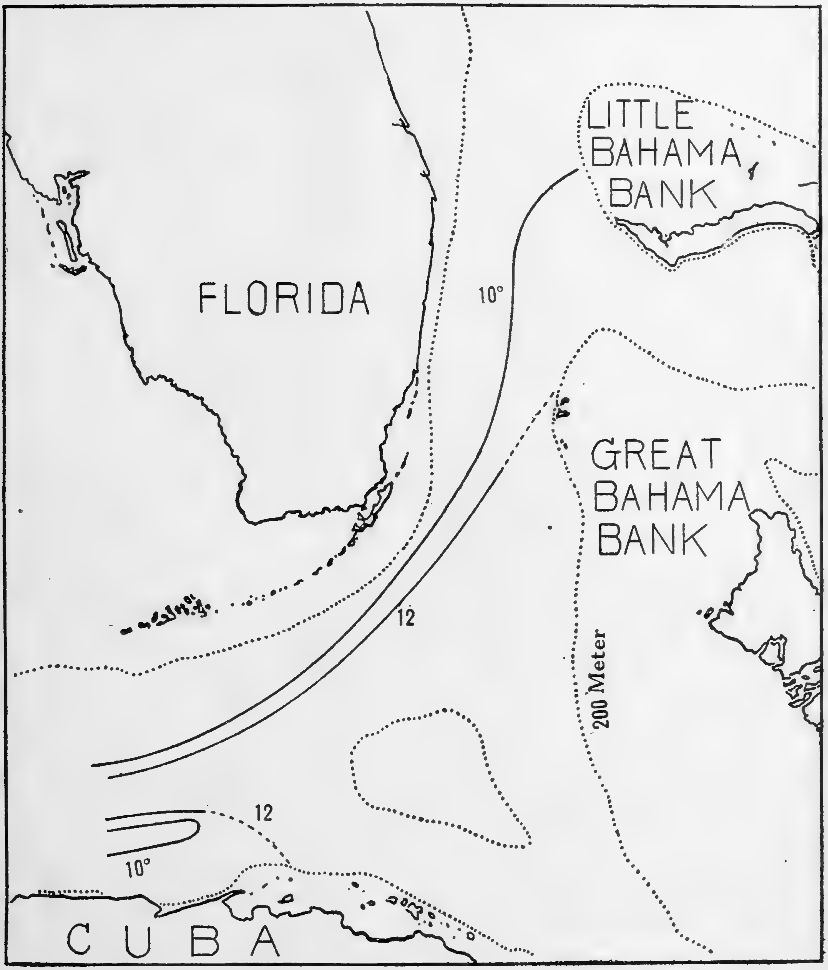

FIG. 39.—Temperature at 600 meters in the Straits of Florida, March, 1914.

The *Blake* profile (Agassiz, 1888) on the Cape Florida-Gun Cay line shows that water colder than 10° was much nearer the surface in 1878 than in 1914, although the temperature in the bottom of the channel was very nearly the same (5.5° to 6.1°) for the two years. Near the surface, however, the *Blake* temperatures taken in May were higher than the *Bache* readings in March, the temperature sec-

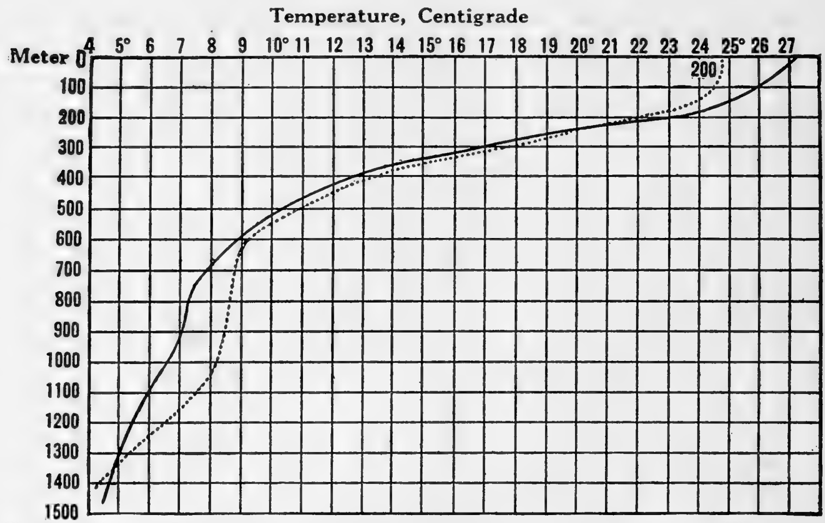

FIG. 40.—Temperature sections taken off Habana, Cuba, March, 1914, by the *Bache* (station 10200), (........), and off Port Muriel, Cuba, by the *Blake*, May 12, 1878 (______).

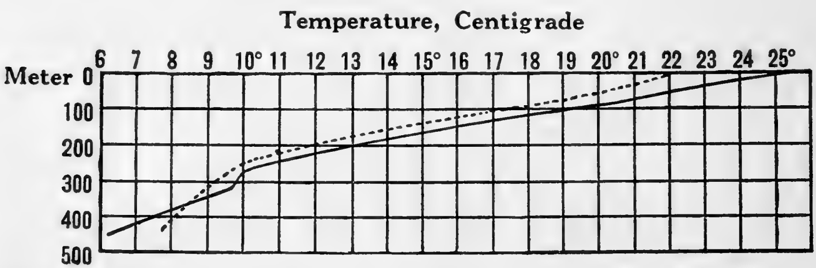

FIG. 41.—Temperature sections taken off Key West by the *Bache* (stations 10197, 10198), March, 1914, (.......), and off the Tortugas by the *Blake*, May 11, 1878 (______).

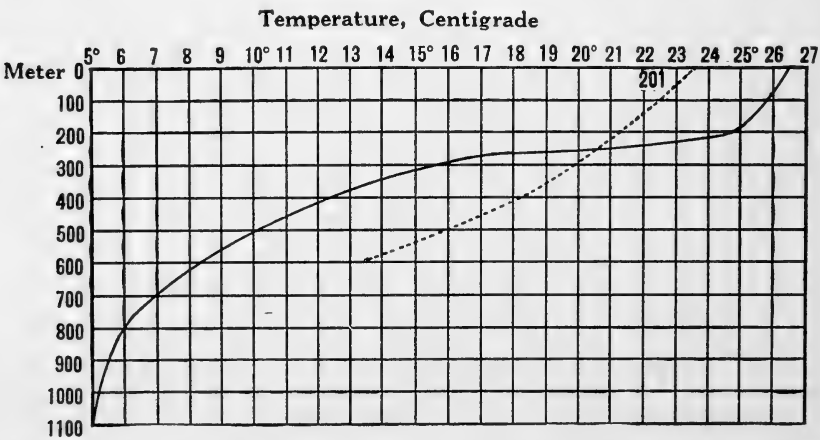

FIG. 42.—Temperature sections in the center of the Straits, between Florida and Cuba, by the *Bache* (station 10201), (........), and by the *Blake*, May 11, 1878 (______).

tions showing that seasonal warming had progressed down to about 100 meters at that season.

The fact that cold water was banked up against Florida in both years is evidence that the general distribution of temperature encountered by the *Bache* is the normal condition for the Straits; but there

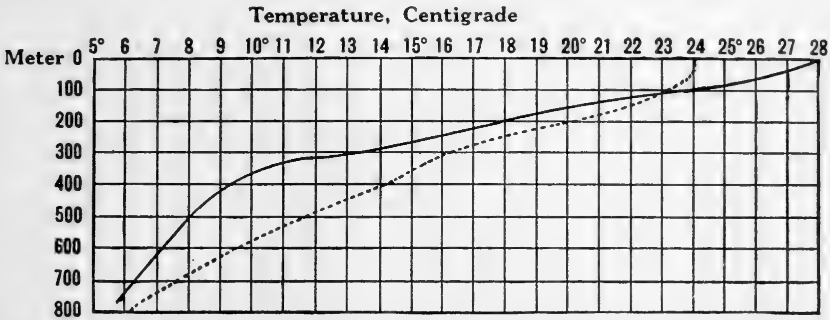

FIG. 43.—Temperature sections in the middle of the Straits between Gun Cay and Cape Florida, *Bache* (station 10203), ..., and by the *Blake*, May 30, 1878, ________.

are evidently considerable variations from year to year in the absolute temperature in the middepths, which probably depend on variations in the deep-water currents of the Straits.

It is, of course, common knowledge that a very strong surface current flows out of the Gulf of Mexico via the Straits of Florida,[a] but

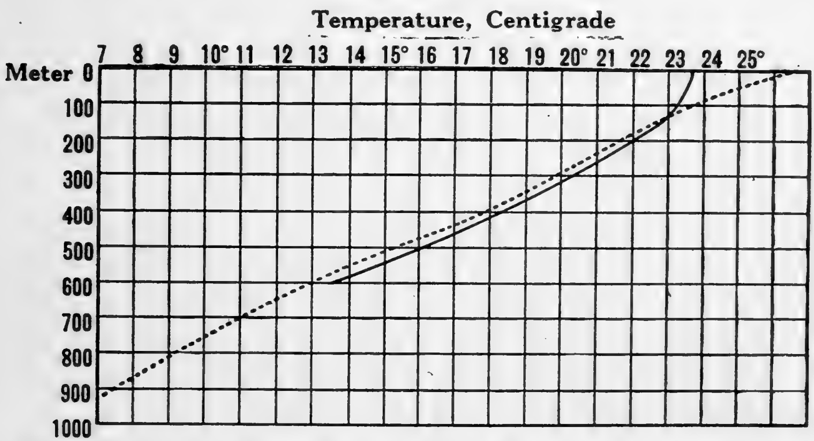

FIG. 44.—Temperature sections 40 miles northeast of Habana, March, 1914, *Bache* (station 10201), ________ and about 95 miles northwest of Habana, May 17, 1876 (*Blake*). ....

information as to the movements of the water in the deeper parts of the Straits is scanty. Mitchell (1869), it is true, believed that he found both velocity and direction constant down to 600 fathoms off the Cuban coast, and his conclusion was accepted by Alexander

[a] For an excellent summary of the history of the Gulf Stream, see Krümmel (1911), p. 574.

Agassiz (1888). The explorations by the United States Coast and Geodetic Survey (Pillsbury, 1886, 1887, 1889) show that an imperfect method of observation had much to do with this result, measurements with current meters at numerous stations demonstrating that as a whole the current was strongest on the surface, decreasing progressively with depth; and although it was still perceptible and sometimes as strong as the surface current at 130 fathoms (237 meters), the lowest level at which readings were regularly taken, the rate of decrease suggested comparative stagnation below about 250 fathoms (457 meters). Although the *Bache* made no actual current measurements, yet the difficulties encountered in using the oceanographic apparatus showed that the current ran very much more rapidly on the surface than in the middepths.

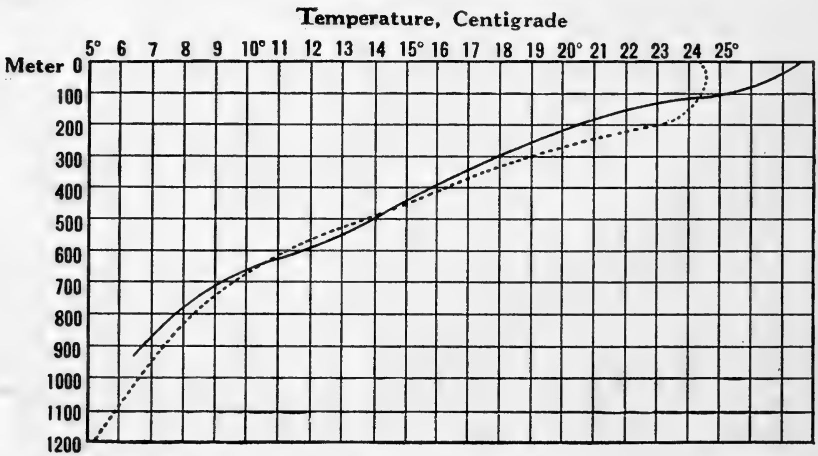

FIG. 45.—Temperature sections off Habana, March, 1914. *Bache* (station 10199), ..., and off Cape San Antonio, May 22, 1878 (*Blake*) (________).

But densities show that the water can not be stagnant in the bottom of the channel, for water of 1.03 is higher at its exit than at its entrance, a state of instability which can only be maintained in one of two ways—i. e., either by a movement of abyssal water from the Gulf of Mexico up the slope of the channel, or by a cold bottom current from the Atlantic. The last supposition has nothing except the persistent and still popular tendency to credit all cool water along our coasts to the Labrador current [a] to support it. On the contrary, as Agassiz long ago pointed out, the fact that the general temperature of the Straits is the same as that of the mass of water west of it, but considerably lower than that of the Atlantic water into which it debouches, in itself seems to forbid the possibility that the cold water in the Straits of Florida comes from the north. A study of the *Blake* temperature sections on successive

[a] Sumner (1913); Soley (1911).

lines normal to the coast, from Cape Canaveral northward (Agassiz, 1888, fig. 176), shows that except on the immediate surface the Gulf Stream retains its character as a cool current as far as Cape Fear, beyond which it is indistinguishable from the water farther to the east. Furthermore, the evidence of salinity is, if anything, even more conclusive, because while the bottom water of the channel (34.8–34.9°/₀₀) is continuous with the abyssal water off Habana at its west end and hence of the Gulf, off the Bahamas water of this salinity was encountered only below 1,800 meters, a vertical drop of 1,000 meters from the exit of the channel. Hence, to suppose that the bottom water of the Straits enters from the Atlantic abyss, we must assume a vertical upwelling of 1,000 meters, of which there is no evidence whatever. And it can not be coastal water from the north, because far too salt. In short, it is clear that the bottom

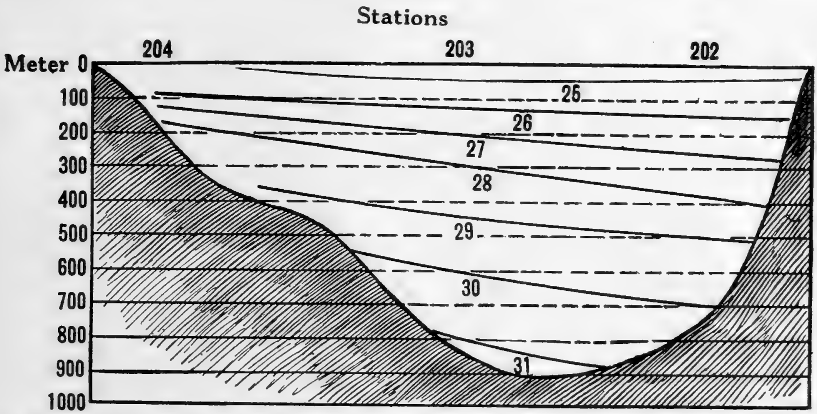

FIG. 46.—Profile of density, at temperature *in situ* and corrected for pressure, across the Straits of Florida, Gun Cay to Cape Florida.

current in the Straits must flow in the same direction as the surface current—i. e., from the Gulf of Mexico—driving the heavy abyssal water of the latter (1.03+) up the slope, thus producing the density gradient mentioned above. This bottom current must be constant, or nearly so, since the rise of cold comparatively fresh water from the deeps of the Gulf up the rising floor of the Straits to near the surface at its exit is now shown to be a permanent phenomenon. In short, the countercurrents occasionally detected by Pillsbury on the bottom on the Florida side of the channel at about 100 fathoms, like the surface countercurrents so long recognized by mariners, are merely local reaction phenomena, or eddies. However, the velocity of the bottom current is certainly only a fraction of the surface drift; and it may be very small indeed.

The close agreement between the salinity of the bottom of the Straits and that of the water in the Atlantic abyss is not the least interesting discovery made by the *Bache*, for it shows that the salinity of the water which flows into the Caribbean Sea through the bottom of the Windward Passage (between Cuba and Haiti), the Anegada Passage (between Sombrero and the Virgin Islands), and possibly the passages between Dominica, Martinique, St. Lucia, and St. Vincent, and thence into the Gulf of Mexico via the bottom of the Yucatan Channel, is unaltered during its sojourn there, a generalization which also holds for temperature, as pointed out by A. Agassiz (1888, p. 220).

The vertical distribution of temperature in the upper layers on the southern half of the Key West–Habana line is generally similar to that of the southwestern part of the Gulf and Straits of Yucatan. In spite of the interval of 40 years between the two sets of observations, the temperature at *Bache* station 10021 agrees almost exactly, down to 800 meters, with the temperature encountered by the *Blake* on May 17, 1876, about 95 miles northwest of Habana, except for being cooler at the immediate surface, a difference to be expected because of the different seasons. And the slightly cooler water off Habana (station 10199) was almost exactly identical with the temperatures taken by the *Blake* in 1878 on the east side of the Yucatan Channel close to Cape San Antonio, except, as before, for a seasonal difference on the immediate surface.

The much colder and fresher water off Key West must have a twofold origin. Probably it comes chiefly from the current which flows around the northern and eastern sides of the Gulf, following the 200-meter curve (British Admiralty, 1897; Soley, 1911). This current is considerably colder at all depths down to about 800 meters than the water in the central and southern parts of the Gulf, as shown by temperatures taken off Apalachicola, Fla., by the United States Fish Commission steamer *Albatross* [a] on March 13, 1885, receiving its low temperature from the cold water in the northwestern part of the Gulf (Krümmel, 1907). The water is even colder on the surface at this season along the north shore of the Gulf than in the Straits. However, this cold surface is confined to a very narrow belt (Deutsche *Seewahrte*, 1882) and is probably due to the cold "northers" which blow so often in winter.

The fact that, except for this shallow surface layer, the water was considerably colder close to Key West than the *Albatross* found it in the northern part of the Gulf (fig. 26), indicates that some upwelling was taking place from the deeps of the Gulf. Thus, temperatures suggest that the west end of the Straits is a condensed epitome of the Gulf as a whole, water from the north flowing around the Florida cays, from the center of the Gulf into the center of the

[a] Dredging and other records of the United States Fish Commission steamer *Albatross*, etc.; Townsend, C. H.; Report United States Commission of Fish and Fisheries, 1900, p. 494.

Straits, and from the southern part of the Gulf along the shore of Cuba, into the southern side of the Straits, as into a funnel. Upwelling of bottom water against the coast of Florida grows more pronounced as this tremendous mass of water forces its way farther and farther into the ever narrowing and shoaling channel.

The unity of temperature between the western end of the Straits in 1914, and the Gulf of Mexico as a whole in 1878, is further interesting because it shows that the difference of temperature in the eastern end of the Straits in the two years can not have been due to any intrinsic difference in the reservoir from which the water came, but must have been the result of a greater flow of cold bottom water in 1878 than in 1914. For all that is yet known, this may be a seasonal, not a vicarious or periodic, variation.

The banking up of cold water against Florida is usually classed as the effect of the rotation of the earth, forcing the water out of its course toward the right against Cuba and the Bahama Bank, with consequent upwelling from the deep layers on the left-hand side of the channel, according to Ekman's (1905) theory (Krümmel, 1911, p. 459). The discovery that the cold comparatively fresh water next to Florida is largely true abyssal water from the Gulf of Mexico supports this view. The density profile, Cape Florida to Gun Cay (fig. 46), shows how much lighter, as well as fresher and colder, the water was on the left than on the right side of the current,[a] an illustration of how effective the deflective force of the earth's rotation is in establishing the distribution of temperature and salinity in a current as rapid as the Florida stream.

THE COAST WATER OFF CHESAPEAKE BAY.

Exploration of the coast water was only incidental to the main work of the *Bache*, but stations 10157–10160 off the mouth of Chesapeake Bay, and a series of observations taken on the continental shelf in that same general region in January, 1916 (p. 60), by the Bureau of Fisheries steamer *Roosevelt*, may be discussed here because of their bearing on the general problem of the origin of the coast water and its relationship to the Gulf Stream (Bigelow, 1915, p. 250).

In January, 1913 (*Bache* stations), the temperature from the coast out to the 35-meter contour was between 6° and 7°, practically uniform from surface to bottom. The salinity, however, showed considerable vertical range even in the small depth of 18 meters (30.01‰ on the surface, 33.57‰ on the bottom, station 10157), and at the 35-meter contour the freshest water lay at 20 meters (station 10159), with salter water both above and below (fig. 48),

[a] For discussion of the general problem of the effect of the earth's rotation on ocean currents, see Ekman (1905) and McEwen (1912). For an excellent summary of the results on actual ocean currents, see Murray and Hjort (1912), p. 276.

instead of on the surface. Over the 200-meter contour, always an important zone off the United States coast because of the abrupt change in the slope of the bottom at this level, the temperature was highest at the middepth (station 10160, 100 meters, 12°), with 9° both on the surface and on the bottom, the latter several degrees warmer than the bottom temperature near the coast, in spite of the greater depth (fig. 47). The salinity (fig. 48) also was considerably higher, with a rapid vertical increase from the surface downward to 35.37°/₀₀ on the bottom. Over the 1,800-meter contour, a few

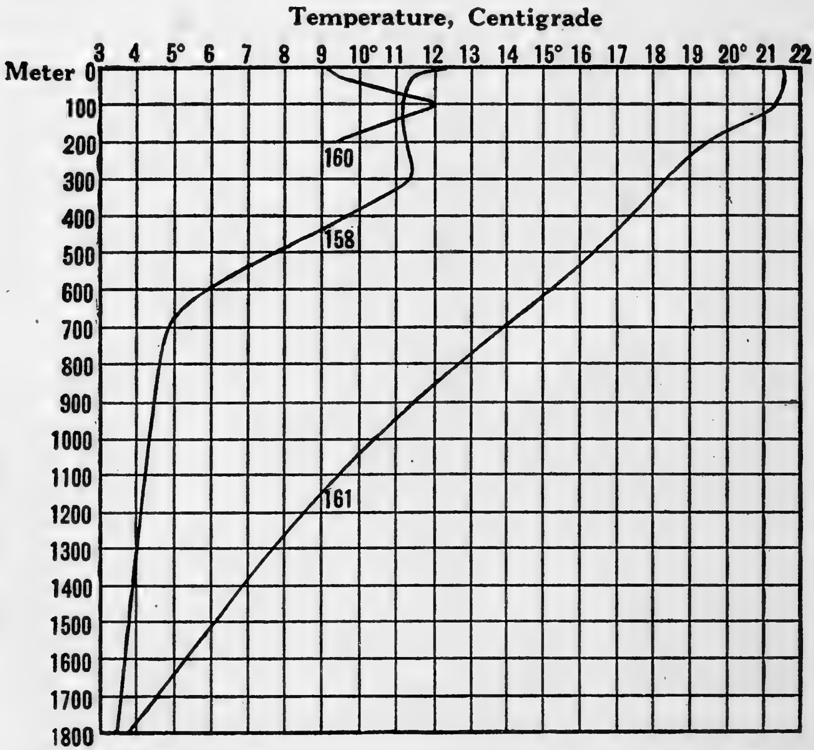

FIG. 47.—Temperature sections off the mouth of Chesapeake Bay, stations 10158, 10160, 10161.

miles outside the continental shelf (station 10158, fig. 47), the water was warmer, depth for depth, being nearly uniform at 11°–12° down to 300 meters, below which level there was a rapid cooling to about 5° at 700 meters, followed by a slow decrease of temperature to 3.55° at 1,800 meters. However, there was no water at this station (fig. 23) as salt as the bottom water over the outer edge of the shelf, the highest salinity being only about 35.19°/₀₀ at 300 meters, with a slow decrease below this level. Near the surface the course of the salinity section is noteworthy, the water being freshest at 20 meters, not on the surface. Eighty-five miles farther offshore (station

10161) the water was much warmer and salter in the upper layers (maximum temperature 21.5°, salinity about 36.45°/₀₀), with a steady decline with depth, the temperature at 1,800 meters being practically the same as at station 10158. Unfortunately, no water sample was taken at that level. The density (corrected for pressure by Ekman's tables of 1910) was lowest at the surface at all these stations, greatest at the bottom (p. 60).

The general temperature profile (fig. 11) shows that at this time the coast water over the shelf and on the continental slope was much colder than the oceanic water farther east at corresponding depths, the transition from one to the other being so sudden that the tem-

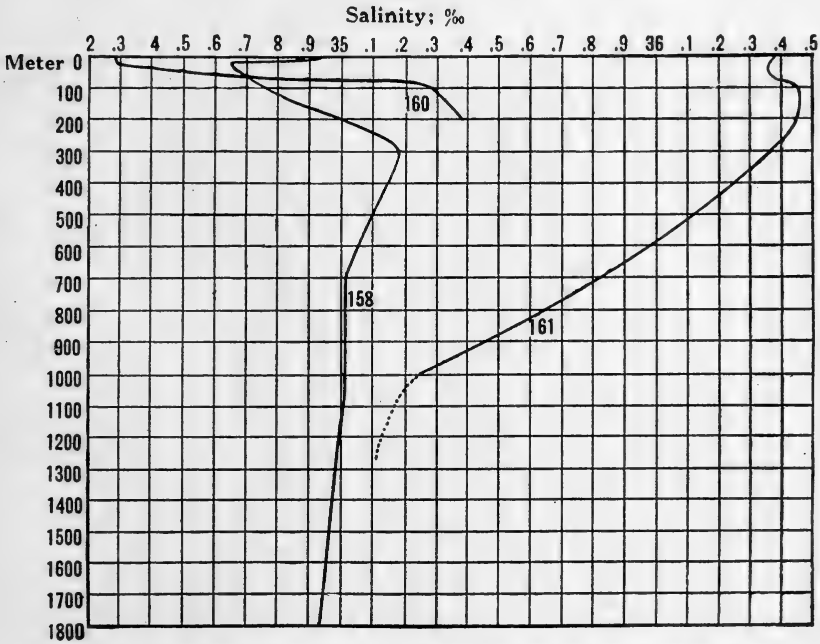

FIG. 48.—Salinity sections off the mouth of Chesapeake Bay; stations 10158, 10160, 10161.

perature curves dip very steeply from land to sea, a typical "cold wall." For example, the 5° curve rises from about 1,000 meters at station 10161 to about 500 meters on the slope in a horizontal distance of 100 miles, and the uniform bottom water of the abyss (4°, and about 35°/₀₀) from about 1,800 meters over the oceanic basin to about 1,200 meters on the slope in the same distance. But the cold coast water (about 6°) was not continuous with the cold water of the abyss, being separated from it by a band of warmer water (9°-10°) washing the bottom at the 200-meter level, and the curves suggest that the bottom water was even warmer (10°–11°) at about 250 meters.

The temperatures over the inner part of the shelf, both vertical and horizontal, were extremely uniform.

Except for its demonstration that the cold coast and abyss waters were discontinuous, the temperature profile does not throw much light on the movements of the water in this region; but the salinity profile (fig. 49) is unusually instructive in this respect. In general, salinity, like temperature, was much lower near the coast than over the oceanic basin, with the same sudden transition from one type of water to the other. The distinction is even sharper in salinity than in temperature, the coast water (33–35°/₀₀) being separated by a

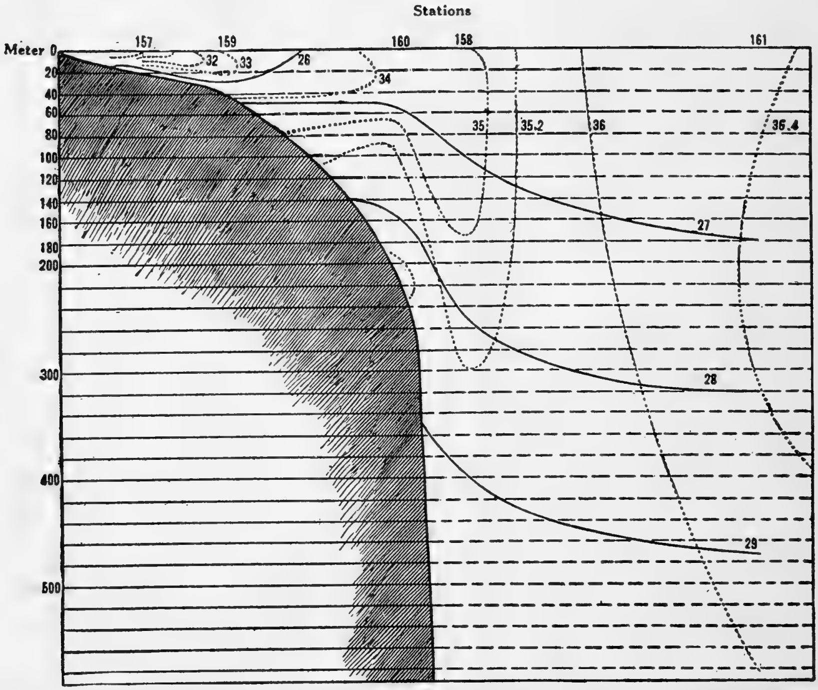

FIG. 49.—Profile of salinity, ..., and density at the temperature *in situ*, ______, from the mouth of Chesapeake Bay, across the continental shelf, to a point 90 miles southeast of the 200 meter contour.

zone of much salter water some 1,000 meters thick from the abyssal water (34.9–35°/₀₀). On the shelf itself there was a steady rise of salinity from the land out to about the 100-meter contour, the curves for successive salinities showing that the axis of freshest water dipped from the surface next the land to about 30 meters at station 10160, overlying considerably salter bottom water. It is over the 200-meter contour that the profile is most instructive, for here water fresher than 35°/₀₀ suddenly dips downward like a tongue into the salter ocean water, and the bottom water of about 35.37°/₀₀ at station 10260 seems to have been entirely surrounded by fresher water.

Such a distribution of salinity obviously suggests that water was flowing down off the shelf into the ocean deeps, and densities are entirely in harmony with this explanation. Thus the water was decidedly denser—i. e., heavier—over the slope (stations 10258, 10260) than at corresponding depths either on the shelf (stations 10157, 10159, p. 59) or in the ocean basin to the east (station 10161, p. 59); hence, would naturally tend to sink. This is further illustrated by the profile (fig. 49), on which all the density curves from the surface down to 500 meters dip sharply toward the ocean basin over the 200-meter contour, and their gradient of about 100 meters in a distance of only 40 miles is steep enough to indicate a very potent dynamic cause for vertical circulation of this type. True, while such a distribution of density suggests a downpour, it does not prove it, because more or less similar densities might result from the opposite process—i. e., an upwelling of heavy water from the abyss over the slope. But when we add the facts that this dense water exactly coincides with the fresh tongue just described, and that the tongue is absolutely separated from the abyss by considerably salter water in the middepths, there is no escape from the conclusion that a downpour or waterfall was actually taking place. If any further confirmation be needed, it is supplied by the fact that the temperature of the axis of this tongue of 34.5–35°/₀₀ water (station 10158) was almost uniform (11°–12°) from the surface down to 300 meters—i. e., to almost exactly the depth to which the curve for 35.2°/₀₀ salinity dips—below which there was a rapid cooling to the considerably lower temperatures (4°–5°) of the abyss. Had upwelling been active, just the reverse—i. e., a sudden vertical cooling in the upper layers—would have obtained.

The sudden cooling (fig. 47) and the reversal of the vertical change in salinity (fig. 48) at 300–700 meters over the slope (station 10158) marks this zone as the lower limit to the downward flow. The uniform abyssal temperature (about 4°) and salinity (about 34.9–35°/₀₀) was encountered here at about 1,200 meters; but in the ocean basin to the east, and, indeed, along the whole line to Bermuda, the upper limit to this abyssal water was at about 1,800 meters (p. 16, fig. 11, 12). So uniform is this water over the north Atlantic as a whole (Krümmel, 1907), and so closely do the curves for 35°/₀₀ and 4° coincide, that this difference in level is only explicable as the result of upwelling over the lower part of the continental slope, the first time we have actually been able to demonstrate this type of circulation on any large scale off our coast (1915). So far as true abyssal water is concerned, this updraught did not rise above about 1,000 meters; but the close agreement between the salinity and temperature of the bottom water on the slope (station 10160) and of the water of the midzone at 1,300–1,400 meters to the east (stations 10161, 10163, 10166) suggests that the latter also was involved, moving up the slope to within about 200 fathoms of the surface. All this, of course, suggests that upwelling from the middepths may play a rôle of some importance in the maufacture of the zone of mixed water along the continental slope, though there is no evidence that oceanic upwelling ever reaches the continental shelf, as Petterson (1897), Clark (1914), and others have supposed. But while there may have been an updraught over the slope shortly previous to the cruise of the *Bache*, nothing of the sort was taking place at that time, because the bottom water at station 10260 was then entirely cut off from the equally salt midlayers by the lower salinities at station 10258 (p. 48).

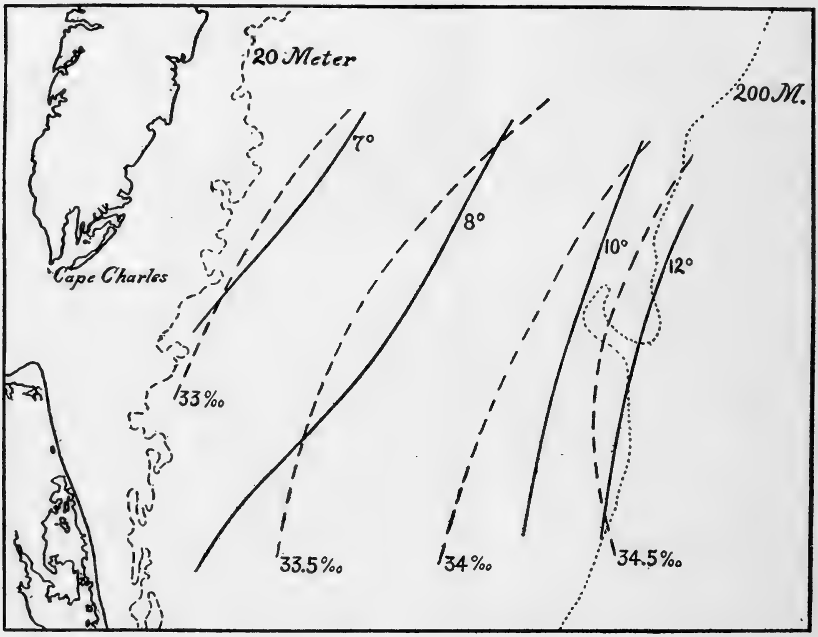

FIG. 50.—Temperatures, ———, and salinities, — — —, off Chesapeake Bay at 20 meters, January, 1916 (*Roosevelt* stations).

A simple explanation for the fact that the descending tongue did not actually follow the slope, but was separated from it by a layer of salter, cooler water, is that the latter is merely a contrast phenomenon, the water preexisting along this part of the slope cut off by the downpour. The single *Bache* profile, unfortunately, is not sufficient to clear up this question. The existence of the downpour and of upwelling below 1,000 meters, however, is amply demonstrated.

The more complete survey of the shelf abreast of Chesapeake Bay carried out by the *Roosevelt* in 1916 (p. 45, 60) shows that the temperature was as uniform vertically in January, 1916, as in the corresponding month of 1914, the greatest vertical range at any station inside the 100-meter contour being only about 2° (p. 60), and that the temperature rose, passing offshore, from about 6°–7° near the land to 10°–12° over the continental slope, just as in 1914 (fig. 50); but the coast water as a whole was 1°–2° warmer at corresponding localities and depths in 1916 than in 1914.[a] Unfortunately the *Roosevelt* lines did not run offshore far enough to meet the warm "Gulf Stream" water.

The salinities for the two years likewise agree, in so far as they rise from the land seaward (fig. 50), and in the flooding of the surface next to the land with water fresher than 30°/₀₀. But in 1916 the water over the shelf between the 20 and 100 meter contours was practically uniform from surface to bottom, and the coast water as a whole was slightly salter than in 1914.

A difference far more important, if anything more than apparent, is that the profiles for 1916 (fig. 51, 52) do not show anything comparable to the downpour outside the slope, so unmistakable in 1914; but it is possible that something of the sort would have appeared, had the profiles run far enough offshore to reach the warm ocean water, for the curves for 35°/₀₀ and 35.2°/₀₀ salinity strongly suggest the corresponding values for 1914 (fig. 49), so far as they go. Assuming the density of the ocean water to have been about the same in 1916 as in 1914, which was probably the case, there would have been the same dynamic tendency for the water over the slope to sink, in 1916 as in 1914, because the density was practically the same, at corresponding locations on the slope, for the *Roosevelt* as for the *Bache* stations (p. 59, 60). There is nothing in temperature to forbid it; on the contrary, the fact that water colder than 10° projected seaward from the shelf into the warmer water offshore in 1916 (fig. 51) distinctly indicates a seaward flow at about the 50-meter level; and the temperature curves over the slope for the two years are readily reconciled with each other on the assumption that the seaward flow over the outer part of the shelf was localized in the upper 30 meters in 1914, as indeed salinity demands, whereas in 1916 it was rather deeper. In 1916 the slope, at 150–250 meters, was washed by water of 12°, a typical warm belt of the sort we are familiar with further north in summer (Bigelow, 1915), whereas in 1914 there was no bottom water warmer than 10° along this line. But as winter cooling seems to have progressed further by the end of January in 1914 than in 1916, this difference is, to all intents and purposes, a seasonal one.

The salinity of the downward flowing tongue of January, 1914 (34–34.5°/₀₀), together with its comparatively low temperature, identifies it as the mixed water resulting from the contact of ocean with coast water. This contact, as is well known, takes place all along the continental slope as far north as the Grand Banks of New

[a] The minimum temperature was lower in 1916 (station 8451, 5.8°) than in 1913 (station 10157, 6.2°); but this difference may be due to different geographic locations.

Foundland. But whether the water thus manufactured tends to sink, or float, depends on the density resulting from the precise temperature and salinity at any given locality, compared to that of the upper 300 meters or so in the warmer, but salter, water east of it. And, unfortunately, the relative densities of the two, off our coasts, are only known off Chesapeake Bay, and along a profile some 40 miles

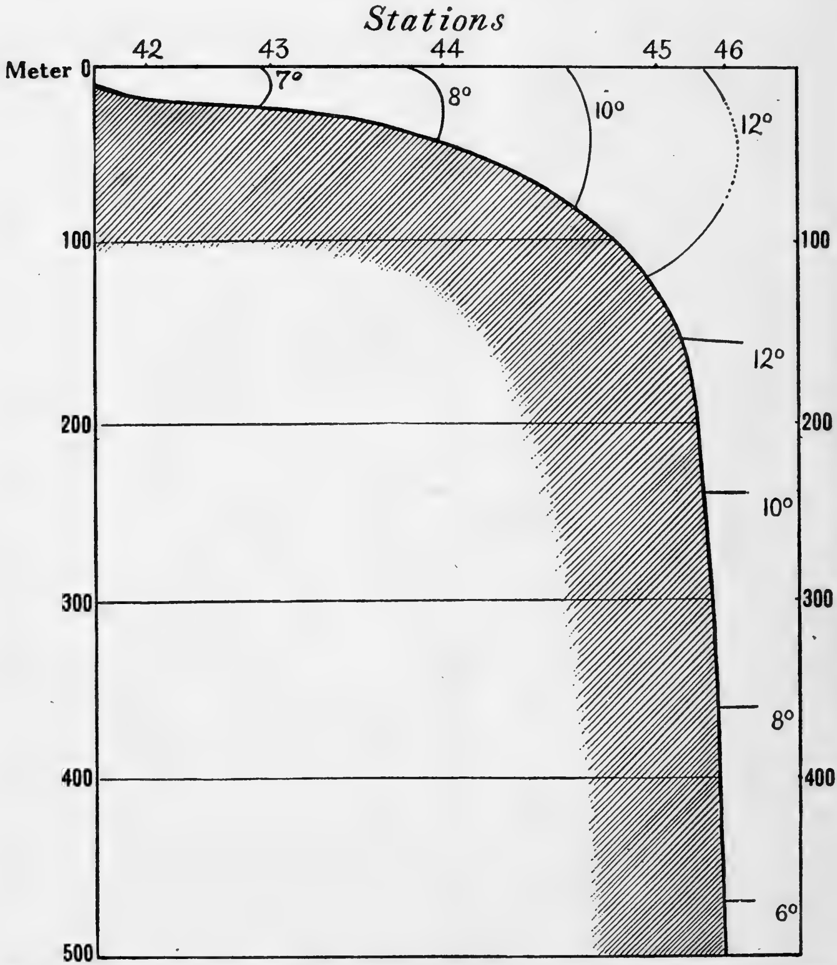

FIG. 51.—Temperature profile across the continental shelf off Chesapeake Bay, January, 1916 (*Roosevelt* stations 8442, 8443, 8444, 8445, 8446).

east of Cape Cod, run by the *Grampus* in July, 1914, none of our other profiles across the slope having reached the undiluted ocean water. The density of the mixed water, however, is fairly well known for the summer season from Chesapeake Bay to Nova Scotia (Bigelow, 1915). But comparison between the two waters may fairly be extended beyond these actual records, for it is safe to assume that the ocean density at any given latitude is at least no higher in summer than in winter; probably lower, because of solar warming, there being no reason to expect any great change in salinity outside the zone influenced by the coast. If this be true, there is the same dynamic tendency for the mixed water at the 50–150 meter level, over the slope off Chesapeake Bay, to sink in summer as in

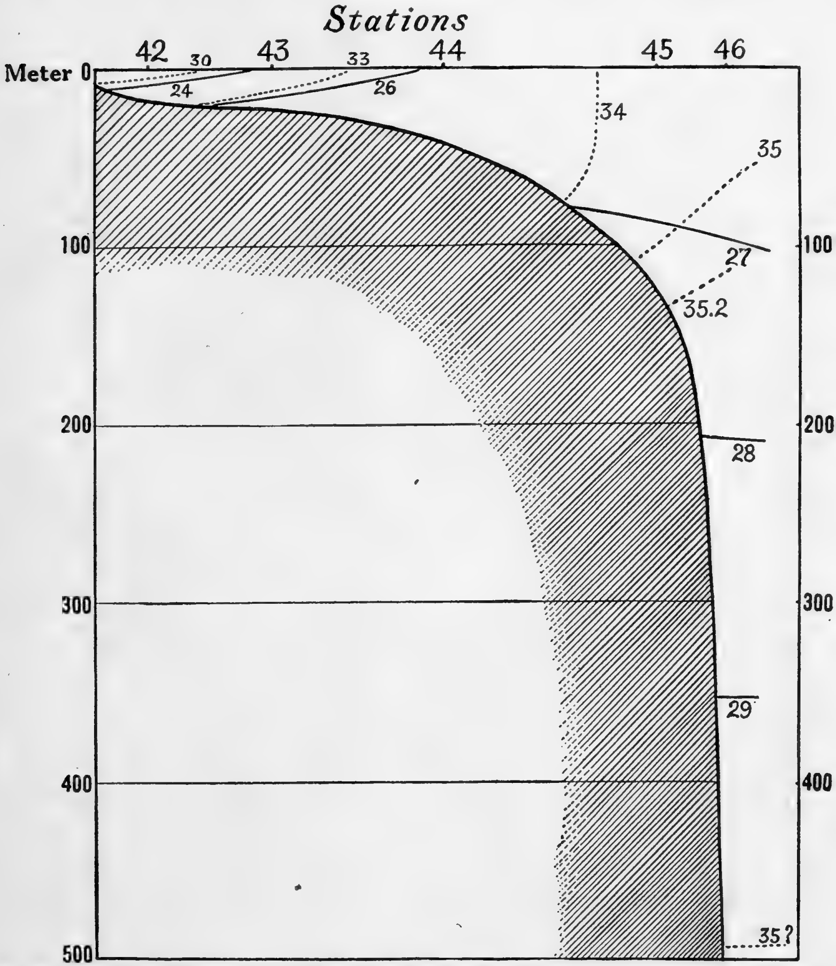

FIG. 52.—Salinity profile across the continental shelf off Chesapeake Bay, January, 1916 (*Roosevelt* stations 8442, 8443, 8444, 8445, 8446).

winter, because the densities are practically the same there for the two seasons (*Bache* station 10158; *Grampus* station 10176, Bigelow, 1915, p. 345) except on the immediate surface, where the water was so light in summer that it must have been floating out over the ocean water offshore (Bigelow, 1915). And summer densities were almost precisely the same, at the same relative position, off Delaware Bay (Bigelow, 1915, station 10171) as off Chesapeake Bay, in 1913 (fig. 53).

Only off Chesapeake Bay is the actual density of the mixed water known for winter. But inasmuch as winter cooling, off our coasts, is most rapid and most extreme next the land (Bigelow, 1915), while the salinity of the coast water, so far as known, rises during autumn and winter (Bigelow, 1915), it follows that the mixed is heavier than ocean water in winter all along our coast, as it certainly is off Chesapeake Bay (p. 49).

But while the actual occurrence of a downpour over the slope can be considered as demonstrated off Chesapeake Bay in winter, and off Georges Bank in summer, our summer profiles across the shelf at intermediate points would be hard to reconcile with this type of vertical circulation (Bigelow, 1915). It is possible that a local

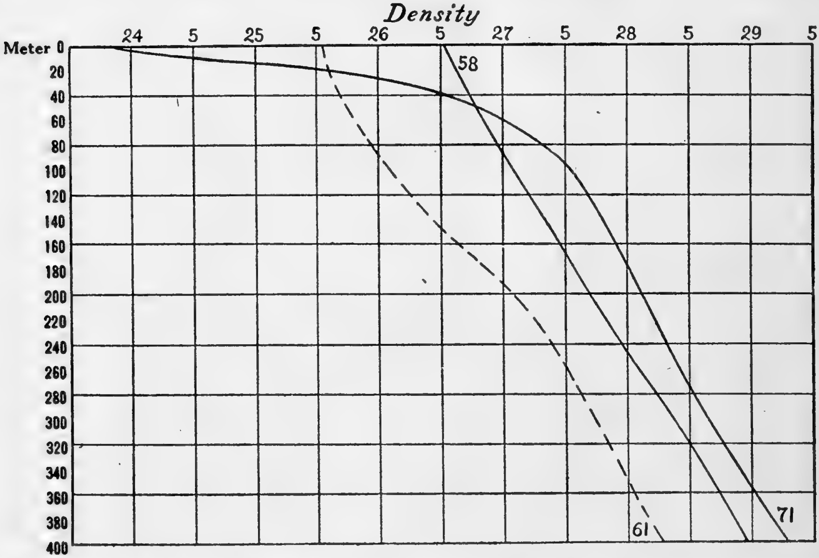

FIG. 53.—Density sections in the ocean water (*Bache* station 10161), and in the mixed water (*Bache* station 10158), off Chesapeake Bay, January, 1914, and in the mixed water (*Grampus* station 10171), off Delaware Bay, July, 1913.

dynamic tendency of this sort might be overridden by some more wide-spread type of oceanic circulation. But whether the downpour be general for the zone over the continental slope, or only local or temporary, the fact that it actually occurs is one of the most interesting hydrographic results of the cruise of the *Bache*, for whenever anything of the sort takes place the mixed water must play as important a rôle in the manufacture of the deeper layers of the coast water on the shelf as it does in the Gulf of Maine.

Finally, it is shown that there is nothing in the *Bache* or *Roosevelt* temperatures to suggest the "Arctic" current so often invoked off our coasts (Bigelow, 1915), the coast water being far too warm even in January.

TABLE OF SALINITIES AND TEMPERATURES; "BACHE" STATIONS, 1914.

Date.	Station.	Lat. N.	Long. W.	Depth.	Salinity.	Temperature.
		° ′	° ′	*Meters.*	‰	° C.
Jan. 20	10157	36 46	75 38	0	30.01	6.20
				18	33.57	6.75
Jan. 21	10158	36 12	74 25	0	34.94	12.30
				20	34.67	11.45
				100	34.76	11.15
				300	35.19	11.40
				700	35.01	4.78
				1,100	35.01	4.20
				1,800	34.94	3.55
Jan. 26	10159	36 35	75 20	0	33.04	7.00
				20	32.95	6.85
				36	33.22	6.75
Jan. 26–27	10160	36 12	74 41	0	34.29	9.15
				20	34.29	9.40
				100	35.28	12.00
				200	35.37?	9.45
Jan. 27	10160½	......	......	0	36.08	22.20
Jan. 28	10161	35 27	73 14	0	36.38	21.50
				20	36.35	21.50
				100	36.44	21.35
				200	36.44	19.60
				600	35.99	15.20
				1,000	35.25	10.40
				1,800	....	3.70
Jan. 29	10162	34 41	73 23	0	36.44	19.30
	10162½	34 03	73 30	0	36.49	18.80
	10163	33 22	73 37	0	36.49	18.95
				20	36.53	18.90
				100	36.44	18.85
				200	36.49	18.90
				600	36.08	15.70
				1,000	35.41	10.05
				1,800	34.97	3.80
Jan. 30	10163½	33 02	73 38	0	36.44	19.90
	10164	32 29	73 28	0	36.56	20.70
	10165	32 32	72 55	0	36.53	20.40
	10166	32 33	72 14	0	36.45	19.15
				20	36.47	19.20
				100	36.45	18.80
				200	36.42	18.30
				600	36.08	15.80
				1,000	....	10.00
				1,800	....	4.05
Jan. 31	10167	32 31	71 53	0	36.49	19.30
	10168	32 28	71 41	0	36.53	19.10
Jan. 31–Feb. 1	10169	32 29	71 29	0	36.44	18.95
				20	36.38	19.00
				100	36.44	18.85
				200	36.42	18.83
				600	36.26	15.60
				1,000	....	10.50
				1,800	35.01	....
Feb. 2	10170	32 18	71 12	0	36.40	18.90
	10171	32 27	69 55	0	36.45	18.95
				20	36.44	19.03
				100	36.45	18.84
				200	36.44	18.65
				600	36.08	16.10
				1,000	35.71	6.70
				1,800	34.99	4.00
Feb. 3	10172	32 26	69 21	0	36.45	18.90
Feb. 4	10173	32 27	68 22	0	36.44	18.85
				20	36.44	18.90
				100	36.42	18.70
				200	36.44	18.10
				600	36.17	16.50
				800	35.64	13.10
				1,000	....	11.60
				1,400	35.46	5.55
				1,800	34.96	3.90
				3,650	....	....
				4,570	34.87	....
Feb. 5	10174	32 28	67 41	0	36.44	18.90
	10175	32 28	66 28	0	36.38	18.90
				20	36.38	18.90
				100	36.36	18.90
				200	36.45	18.90
				600	36.17	16.30
				1,000	....	....
				1,800	....	4.20
	10176	32 30	65 48	0	36.44	19.20

TABLE OF SALINITIES AND TEMPERATURES; "BACHE" STATIONS, 1914—Continued.

Date.	Station.	Lat. N.	Long. W.	Depth.	Salinity.	Temperature.
		° ′	° ′	Meters.	‰	° C.
Feb. 6	10177	32 32	65 12	0	36.42	19.10
				20	36.40	18.95
				100	36.44	18.95
				200	36.42	18.97
				400	36.35	17.40
				600	36.00	15.50
				1,000	....	....
				1,200	35.05	11.55
				1,500	....	4.35
				1,800	34.99	3.60
Feb. 17–18	10178	32 20	64 21	0	36.42	18.80
Feb. 18	10179	32 12	64 42	0	36.40	18.64
				20	36.44	18.40
				100	36.44	18.50
				200	36.42	18.52
				400	36.31	17.15
				600	35.90	14.52
				800	35.77	13.74
				1,000	35.37	9.65
				1,800	34.99	4.40
Feb. 18–19	10180	31 52	65 14	0	....	18.10
Feb. 19	10181	31 01	65 58	0	36.42	19.37
				20	....	19.28
				100	36.42	18.78
				200	36.44	18.89
				400	36.33	17.13
				600	35.93	15.20
				800	35.37	....
				1,000	35.07	7.38
				1,200	35.03	....
				1,400	....	4.88
				1,500	....	....
				1,800	35.01	3.89
Feb. 19–20	10182	30 27	66 05	0	36.56	20.12
Feb. 20	10183	29 32	66 25	0	36.62	21.00
				20	....	19.97
				100	36.62	20.89
				200	36.53	19.22
				400	....	17.41
				600	36.17	16.31
				800	35.73	13.68
				1,000	....	7.67
				1,400	....	5.52
				1,500	....	....
				1,800	....	4.39
Feb. 21	10184	29 17	67 07	0	36.56	20.07
	10185	29 16	67 51	0	36.42	19.80
				20	....	19.89
				100	36.49	19.55
				300	36.35	17.30
				600	35.79	14.40
				800	35.21	9.67
				1,000	35.10	....
				1,200	....	....
				1,400	....	4.44
				1,800	35.01	3.77
Feb. 21–22	10186	29 15	68 35	0	36.47	19.40
Feb. 23	10187	28 59	69 22	0	36.51	19.30
				20	....	19.23
				100	36.49	19.26
				300	36.47	....
				600	36.24	16.44
				800	35.70	13.05
				1,000	35.19	9.05
				1,200	35.05	....
				1,400	34.99	5.08
				1,800	34.99	4.01
Feb. 24	10188	28 51	70 08	0	36.47	19.47
	10189	28 48	70 40	0	36.47	19.66
				20	....	19.63
				100	36.45	20.83
				300	36.45	17.95
				600	36.13	16.18
				800	35.55	....
				1,000	35.08	8.37
				1,200	34.99	....
				1,400	34.99	5.00
				1,800	34.97	4.10

TABLE OF SALINITIES AND TEMPERATURES; "BACHE" STATIONS, 1914—Continued.

Date.	Station.	Lat. N.	Long. W.	Depth.	Salinity.	Temperature.
		° ′	° ′	*Meters.*	‰	° *C.*
Feb. 25	10190	28 42	71 32	0	36.56	20.10
	10191	28 33	72 24	0	36.56	21.42
				20	....	21.39
				100	36.60	18.20
				300	36.33	17.70
				600	35.95	15.11
				800	35.35	11.11
				1,000	35.03	....
				1,200	35.07	5.53
				1,400	....	4.70
				1,800	34.96	3.79
Feb. 26	10192	28 35	73 33	0	36.62	21.58
				4,528	35.03	....
				4,733	35.03	....
Feb. 27	10193	28 43	74 22	0	36.53	21.75
				20	....	21.73
				100	36.53	19.88
				300	36.53	18.01
				600	35.93	14.67
				800	35.19	....
				1,000	35.03	10.05
				1,200	35.05	5.35
				1,400	....	4.54
				1,800	35.01	3.74
Feb. 28	10194	28 51	75 13	0	36.53	21.55
	10195	29	76 23	0	36.49	21.70
				20	....	21.70
				100	36.51	21.38
				300	36.47	17.90
				600	35.82	14.07
				800	35.21	9.87
				1,000	35.03	....
				1,200	35.01	....
				1,400	34.97	4.37
				1,800	34.99	3.74
Mar. 3	10196	25 27	77 16	0	36.58	22.83
				20	....	22.84
				100	36.56	22.82
				500	35.64	12.93
				1,000	35.03	5.20
				3,400	34.92	2.86
Mar. 13	10197	24 18	81 50	0	36.06	20.78
				20	36.02	20.89
				60	36.08	20.59
				100	36.00	15.56
				150	35.66	13.39
				200	35.30	11.03
	10198	23 59	81 50	0	36.11	23.35
				20	36.11	23.06
				100	....	20.34
				200	....	13.98
				400	....	10.36
				900	34.90	7.00
Mar. 14	10199	23 13	81 50	0	35.97	24.34
				20	36.00	24.60
				100	36.06	....
				200	36.53	23.31
				400	36.17	15.93
				600	35.28	11.24
				1,200	34.92	5.03
Mar. 18	10200	23 32	81 48	0	35.93	24.78
				20	35.93	24.72
				100	36.26	24.45
				200	36.58	22.34
				400	35.66	13.51
				600	35.03	9.10
				1,000	34.87	8.31
				1,400	....	4.36
Mar. 19	10201	23 47	81 47	0	36.08	23.61
				400	....	18.37
				600	....	13.45
				1,700	34.94	....
	10202	25 34	79 24	0	36.17	23.35
				20	....	23.30
				100	36.26	23.23
				200	36.67	21.82
				300	36.44	18.71
				400	36.26	16.63
				500	35.81	14.15
				700	35.53	12.17

TABLE OF SALINITIES AND TEMPERATURES; "BACHE" STATIONS, 1914—Continued.

Date.	Station.	Lat. N.	Long. W.	Depth.	Salinity.	Temperature.
		° ′	° ′	*Meters.*	‰	° *C.*
Mar. 20	10203	25 34	79 42	0	36.08	24.03
				20	....	24.03
				100	36.26	23.25
				200	36.53	20.17
				300	35.99	15.95
				400	35.84	14.42
				800	34.85	6.16
	10204	25 33	80 03	0	36.17	21.75
				20	36.20	21.83
				100	36.17	21.07
				150	35.30	10.72
	10205	27 05	79 52	0	36.02	23.60
				20	36.08	22.88
				60	36.22	22.48
				100	36.04	19.19
				175	35.43	12.25
				250	34.85	6.90
Mar. 21	10206	27 17	79 40	0	36.09	23.75
				20	36.11	23.40
				100	36.26	23.40
				200	36.55	20.13
				300	35.82	14.71
				400	35.10	9.68
				500	....	8.53
				700	34.85	5.70
	10207	27 32	79 21	0	36.17	23.70
				20	36.17	23.60
				100	36.20	23.30
				200	36.56	19.93
				300	36.38	17.61
				400	36.08	15.78
				500	35.79	13.90
	10208	27 46	78 46	0	36.42	22.80
				20	36.44	22.42
				100	36.51	....
				200	36.53	19.91
				300	36.42	18.78
				500	36.18	16.39
				700	35.37	10.88
				800	35.03	8.26
Mar. 22	10209	27 57	78 15	0	36.44	22.23
				20	36.45	21.52
				100	36.49	20.65
				200	36.49	18.57
				400	36.11	16.11
				500	35.97	....
				700	35.26	10.08
				800	....	7.41
				900	35.01	5.98
	10210	27 59	77 25	0	36.42	21.78
				20	36.40	21.80
				100	36.51	21.56
				200	36.55	20.80
				300	36.49	17.44
				450	36.31	17.06
				600	36.00	....
				800	....	10.29
				1,000	35.10	6.04
	10211	28 08	76 48	0	36.55	20.98
				20	....	21.02
				100	36.55	20.85
				300	36.42	17.81
				500	36.22	16.29
				700	35.73	13.38
				850	....	8.57
				1,000	35.07	6.64
Mar. 23	10212	28 10	76 18	0	36.60	20.75
				20	36.56	20.80
				100	36.56	20.50
				300	36.26	17.77
				500	35.97	14.62
				750	35.10	10.01
				1,000	35.03	5.62
				1,800	35.01	3.67

Density on Profile Cape Florida–Gun Cay, 1914, Corrected for Pressure by Ekman's (1910) Tables.

Station.	Depth.	Density[a] corrected for pressure.	Station.	Depth.	Density[a] corrected for pressure.
	Meters.			*Meters.*	
10202	0	24.74	10203	0	24.47
	100	25.34		100	25.34
	200	26.65		200	26.83
	300	27.46		300	27.84
	400	28.26		400	28.61
	500	29.04		800	31.09
	700	30.03	10204	0	25.13
				100	25.84
				500	27.74

[a] At temperature *in situ*.

Density off Chesapeake, "Bache" Stations, January, 1913, Pressure Correction from Ekman's (1910), Table 4 Only.

Station.	Depth.	Density[a] corrected for pressure.	Station.	Depth.	Density[a] corrected for pressure.
	Meters.			*Meters.*	
10157	0	23.65	10158	0	26.57
	18	26.40		20	26.63
10159	0	25.92		100	27.08
	20	25.94		300	28.39
	36	26.23		700	31.04
10160	0	26.60		1,100	32.99
	20	26.69		1,800	36.20
	100	27.31	10161	0	25.58
	200	28.50		20	25.64
				100	26.10
				200	27.11
				600	29.60
				1,000	31.90

[a] At temperature *in situ*.

"Roosevelt" Stations Off Virginia Capes, January and February, 1916.

Station.	Bearings. Lat. N.	Bearings. Long. W.	Date.	Depth.	Station.	Bearings. Lat. N.	Bearings. Long. W.	Date.	Depth.
	° ′	° ′		*Meters.*		° ′	° ′		*Meters.*
D8442	36 55$\frac{3}{4}$	75 57	Jan. 27	19	D8450	37 22$\frac{1}{2}$	75 14$\frac{7}{8}$	Jan. 28	28
D8443	36 57$\frac{1}{2}$	75 36	Jan. 27	19	D8451 [a]	37 22	75 24	Jan. 28	13
D8444	36 57$\frac{5}{8}$	75 11$\frac{1}{2}$	Jan. 27	38	D8452	36 35$\frac{1}{2}$	75 44	Jan. 31	20
D8445	36 58	74 41$\frac{1}{2}$	Jan. 27	131	D8453	36 36$\frac{3}{4}$	75 18$\frac{1}{8}$	Jan. 31	26
D8446	36 56$\frac{1}{4}$	74 36$\frac{3}{4}$	Jan. 28	479	D8454	36 36$\frac{5}{8}$	74 58	Jan. 31	38
D8447	37 21$\frac{1}{4}$	74 27$\frac{1}{4}$	Jan. 28	415	D8455	36 37	74 42$\frac{5}{8}$	Jan. 31	60
D8448	37 21$\frac{1}{8}$	74 32$\frac{7}{8}$	Jan. 28	94	D8456	36 37	74 40$\frac{1}{2}$	Jan. 31	340
D8449	37 22	74 40$\frac{5}{8}$	Jan. 28	59	D8457	38 21	73 38	Feb. 1	125

[a] Bell buoy W. $\frac{1}{8}$ N., 1$\frac{1}{2}$ miles.

TABLE OF TEMPERATURES, SALINITIES, AND DENSITIES AT "ROOSEVELT" STATIONS, JANUARY AND FEBRUARY, 1916.

[Density is at the temperature *in situ*, corrected for pressure by Ekman's (1910) tables.]

Station.	Depth.	Temperature.	Salinity.	Density.
	Meters.	° *C.*	‰	
D8442	0	6.11	29.34	23.12
	11	6.67	30.93	24.39
	17	6.67	32.34	25.52
D8443	0	7.22	30.79	24.13
	9	6.95	33.01	25.92
	18	7.11	33.35	26.23
D8444	0	8.33	....	....
	18	7.89	33.64	26.32
	33	8.00	33.62	26.36
D8445	0	11.39	34.63	26.43
	27.5	11.11	34.58	26.63
	55	10.83	34.56	26.68
	131	12.33	35.28	27.46
D8446	0	12.22	34.49	26.20
	55	11.83	34.96	26.81
	110	12.78	35.21	27.06
	183	11.67	35.30	27.73
	238	10.17	35.25	28.26
	478	5.89	35.05	29.84
D8447	0	10	34.38	26.50
	55	10.56	34.76	27.03
	110	12.56	35.19	27.29
	183	11.67	35.35	27.54
	238	10.56	35.21	28.24
	414	7.78	34.94	29.23
D8448	0	10.28	34.38	26.50
	27.5	10.56	34.42	26.59
	55	10.56	34.58	26.82
	92	12.22	35.12	27.14
D8449	0	8.05	33.53	26.14
	27.5	9.33	33.86	26.39
	57.5	10.67	34.69	26.93
D8450	0	6.95	33.35	26.14
	11	7.22	33.37	26.25
	16	7.00	33.37	26.29
D8451	0	5.83	32.57	25.67
	12	6.22	32.52	25.67
D8452	0	7.33	30.25	23.70
	19	7.89	33.17	25.96
D8453	0	8.33	33.64	26.18
	11	8.78	33.68	26.22
	22	8.56	33.66	26.26
D8454	0	8.89	33.96	26.34
	18	9.56	34.02	26.45
	37	10	34.23	26.52
D8455	0	9.33	34.02	26.32
	18	11.11	34.38	26.42
	55	11.39	34.61	26.66
D8456	0	12.22	34.72	26.39
	55	12.22	34.97	26.83
	110	12.67	35.05	27.07
	183	12.50	35.32	27.63
	238	11.89	35.26	27.91
	293	10.56	35.30	28.53
	337	10.11	34.97	28.53
D8457	0	12.50	34.29	25.92
	20	10.83	35.01	26.91
	55	11.11	....	....
	124	11.11	35.16	27.50

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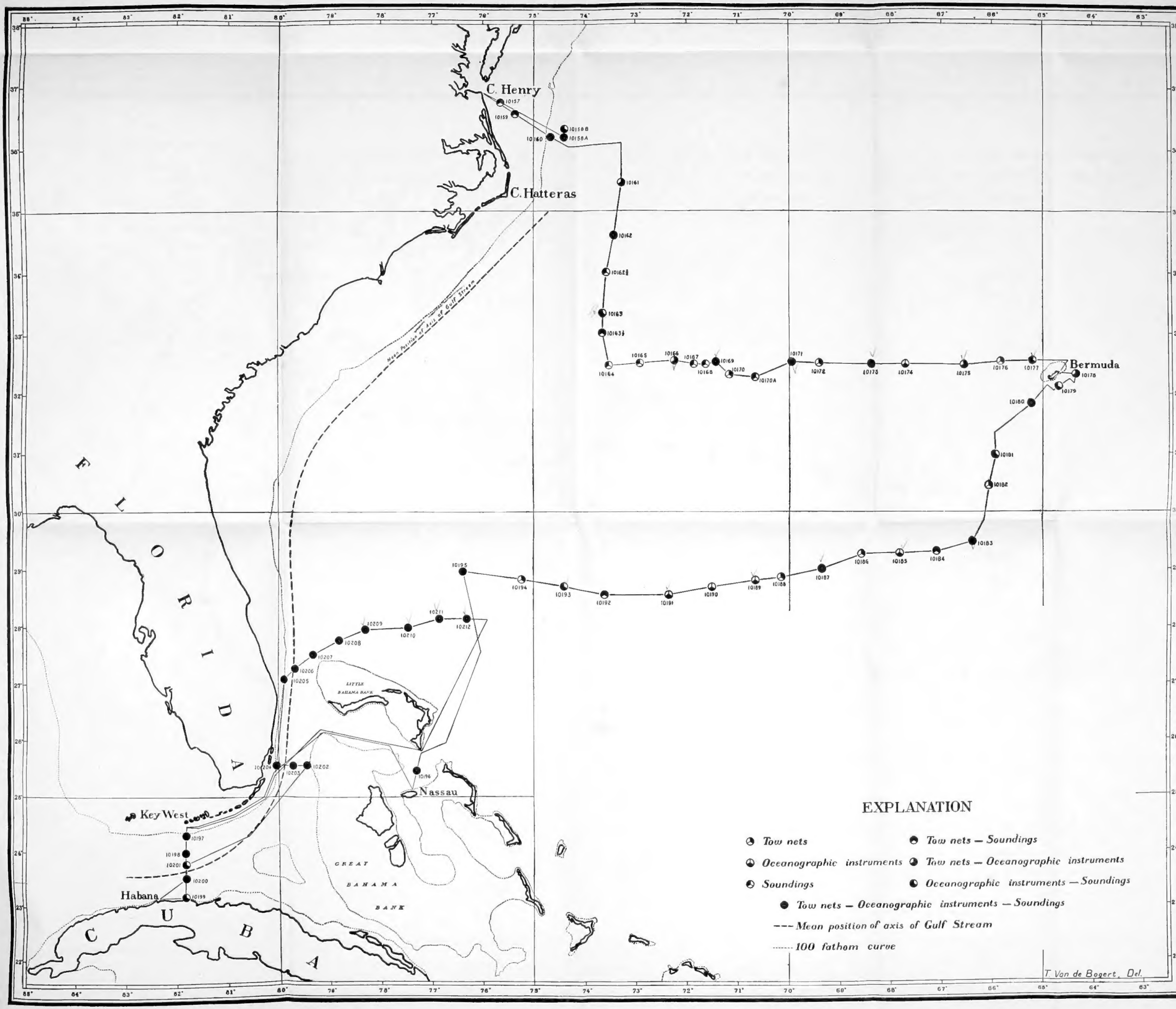

ROUTE OF THE STEAMER "BACHE," JANUARY-MARCH, 1914, WITH LOCATION OF STATIONS.

63271°—17. (To face page 62.)