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A DETAILED STUDY OF THE SURFACE LAYERS OF THE OCEAN IN THE NEIGHBORHOOD OF THE GULF STREAM WITH THE AID OF RAPID MEASURING HYDROGRAPHIC INSTRUMENTS

By

ATHELSTAN F. SPILHAUS

*Woods Hole Oceanographic Institution**
and New York University

INTRODUCTION

In an earlier communication in this Journal the writer reported on a Bathythermograph for obtaining continuous records of temperature against depth in the first 150 meters of the ocean (Spilhaus 1937). While further development of this preliminary instrument revealed it to be rather critical to vibration, the results obtained with it, some of which were reported in the paper cited above, were sufficient to indicate the desirability of further studies and development along these lines. Abrupt changes in the vertical temperature distribution with very small changes in horizontal distance together with extremely complex temperature structure in the vertical were observed in the surface layers. When an attempt was made to reproduce these instruments, various devices were employed in order to shield the bi-metal reed, which was then used as the temperature element, against the vibrational forces as it travelled through the sea water. While these could be reduced to a large extent when the instrument was used under favorable circumstances, it was not found possible to completely eliminate vibrations under all conditions because the bi-metal temperature strip formed an integral part of the recording stylus and had, necessarily, in order to reduce the transient errors in the record when the instrument passed rapidly through a thermoclime, to be exposed to the turbulent flow of the water through the instrument to insure adequate heat transfer to the temperature element. This incompatibility of the requirements was eliminated by the use of the bourdon type element where the bulb of the temperature responsive system may be exposed to the flow while the moving portion, the actual bourdon spiral, may be entirely shielded from flow. This is in essence the basic change made in the new Bathythermograph.

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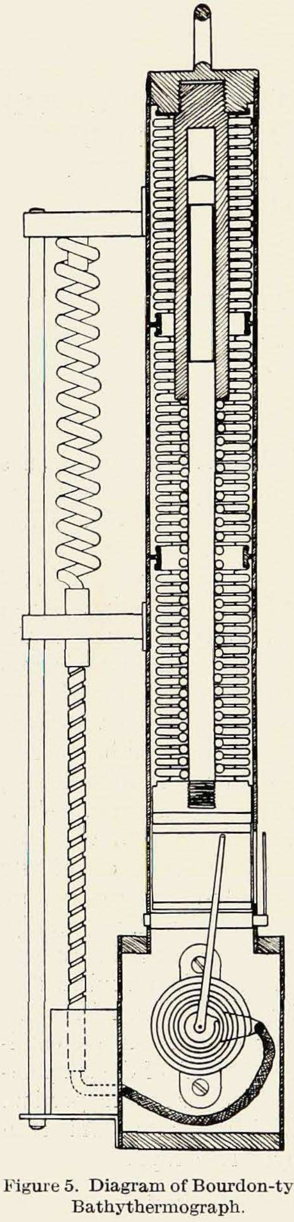

Figure 5. Diagram of Bourdon-type Bathythermograph.

DESCRIPTION OF THE BOURDON TYPE BATHYTHERMOGRAPH

The new Bathythermograph, incorporating the bourdon element described above, is shown in Figure 5. It will be seen that the instrument consists of a pressure responsive element which carries a holder into which a small glass slide may be slipped while the temperature responsive unit is fixed in the body of the instrument so that the slide, which receives the record, is moved parallel to the length of the instrument by pressure changes while temperature changes move the pen across the slide. Thus a plot of temperature against pressure is obtained on the glass. The slide is prepared for receiving the record in an identical fashion to that described by the writer (Spilhaus 1937). Figure 6 shows a photograph of the instrument, together with a box of records, the latter indicating the convenience of the small slides, for, when measurements are made in rapid succession, many hundreds of records may be taken on a single cruise. It may be noticed in the photograph that a Nansen bottle clamp is used to fasten the Bathythermograph to the hydrographic winch wire. This clamp with its tripping mechanism is used also to provide a means whereby, when the instrument reaches the lowest point of the descent into the ocean, a messenger may be sent down the hydrographic wire in the usual fashion to take off the pen, preparatory to the ascent of the instrument, so that only one trace, that of the descent, is obtained. In the case of the Bathythermograph soundings when the vesssel is not moving relative to the water and when the temperature conditions are steady there is considerable value of having both traces and insuring that the two traces correspond as this is an excellent check as to whether the instrument is working perfectly. However, where the instrument was used while under way at sea, it was found that the descent and ascent curve of the instrument might differ quite considerably, not due to imperfect functioning of the instrument but due to the fact that actual horizontal gradients of temperature may be so great in the surface layers that considerable changes of temperature, level for level, are found due to the distance the ship has travelled in the interval between the time the instrument passed the particular level in its descent and the later time when it passed it again during the ascent. This is clearly brought out by examination of the later diagrams. The transient rate of the temperature element was found to be very rapid and certainly sufficient for all practical purposes. This high rate

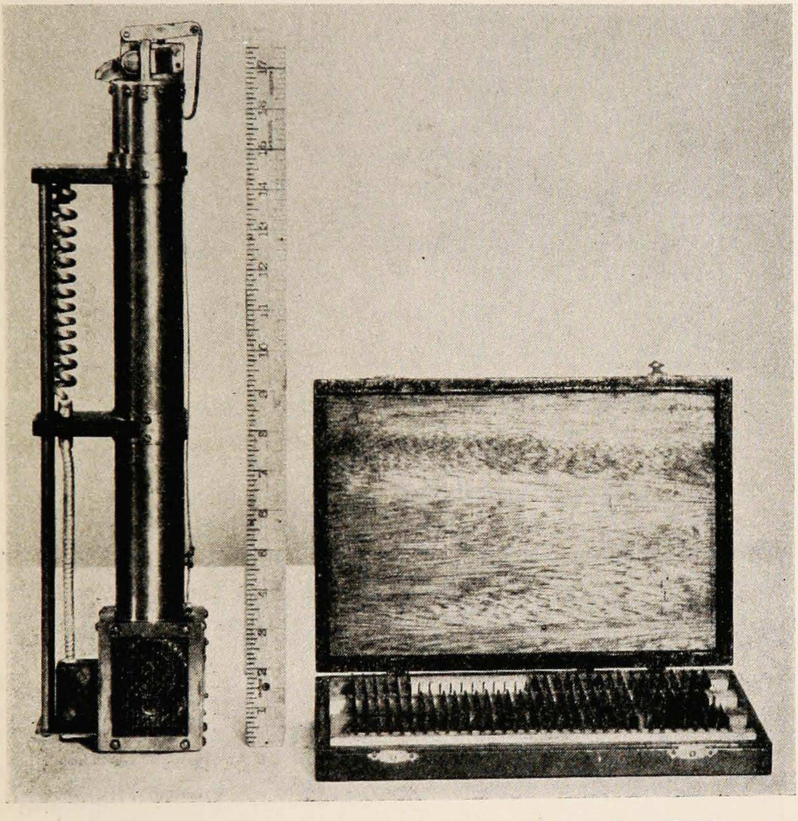

Figure 6. The Bourdon-type Bathythermograph and box of record slides.

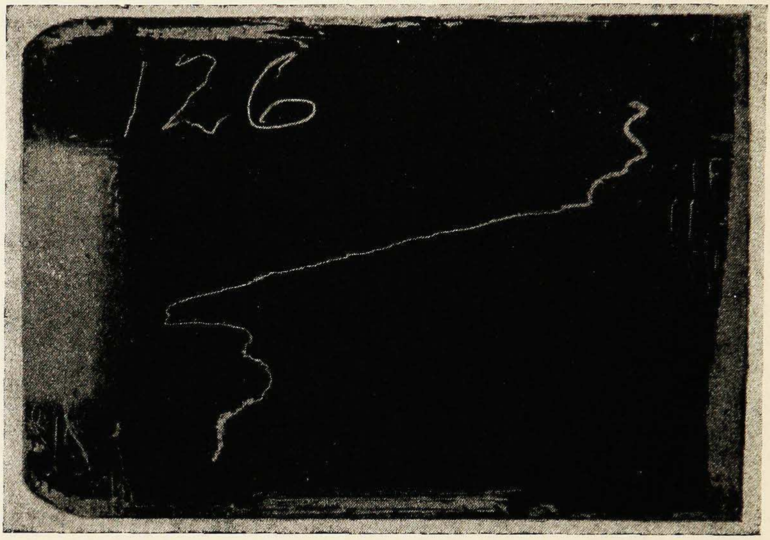

Figure 7. Enlargement of original record from Bathythermograph station No. 126.

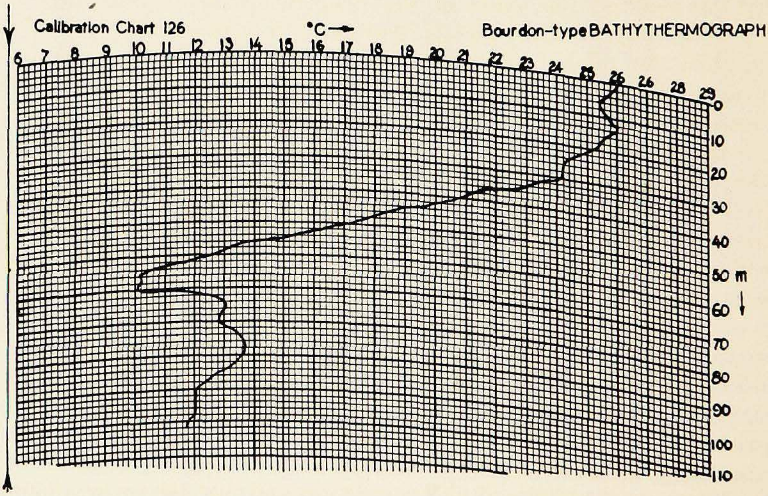

Figure 8. Same record as in figure 7 superimposed upon calibration chart.

of response was obtained by having the bulb constructed in helical form of a tube of small diameter, thereby obtaining a high surface-volume ratio. A typical trace is shown in Figure 7. Figure 8 shows the same trace superimposed on a calibration chart. The rise of temperature of about 3.0° Centigrade between 70 and 73 m. is noteworthy. The instrument was descending at that time at a rate of 20 meters per minute. In other words, this response took place in less than 10 seconds. Similar sharp inversions are observed very often on other records. The method of using the traces obtained on the small glass slides is very simple: a special projector throws an enlarged image of the trace on a frosted glass screen on which may be placed a translucent calibration chart. The graph of temperature against depth is then simply traced with pen or pencil onto the calibration chart. The slide holder in the projector is arranged to be in every respect similar to the holder in the Bathythermograph and, therefore, the slide is held in the same relative position in each. Thus, there is no need of any reference marks on the slide.

So completely did the use of the bourdon thermometer eliminate vibration that it was found the new Bathythermograph could be sent down into the ocean while the vessel was travelling at as high a speed as 11 knots. In fact, not the slightest vestige of vibration was apparent on a record made at this speed, the only difficulty experienced being that a considerable length of wire has to be paid out to get down to the requisite depth. This ability to use the Bathythermograph while travelling at high speed was very shortly recognized as a tremendous advantage because by this means a closer approach to synchronism of observations was made possible.

It was realized the value of the temperature depth soundings taken while under way would be greatly increased if it were possible to develop an instrument for taking salinities at the same time. The ideal solution, of course, would be the development of a recording salinity instrument whereby a continuous record of salinity against depth could be taken, preferably while the ship was in motion. However, the development of such an instrument, while entirely possible, will take some considerable time and it was felt that it is sufficient to have a continuous record of temperature and measurements of salinity at suitably distributed depths. This led to the development of a Sea Sampler for taking samples of the water at various predetermined depths while under way.

DESCRIPTION OF THE PRESSURE-OPERATED MULTIPLE SEA SAMPLER

The requirements to be met in the design of the Sea Sampler were, that wire angle must have no effect on the operation, that the instrument must take a number of samples at different depths and that the whole instrument should not be too bulky and clumsy in operation. The Pressure-operated

Multiple Sea Sampler comprising six sample bottles arranged such that they tripped at a distribution of points down to 150 meters was developed, and the experimental model was built for the writer through the kind cooperation of the Submarine Signal Company of Boston, Massachusetts.

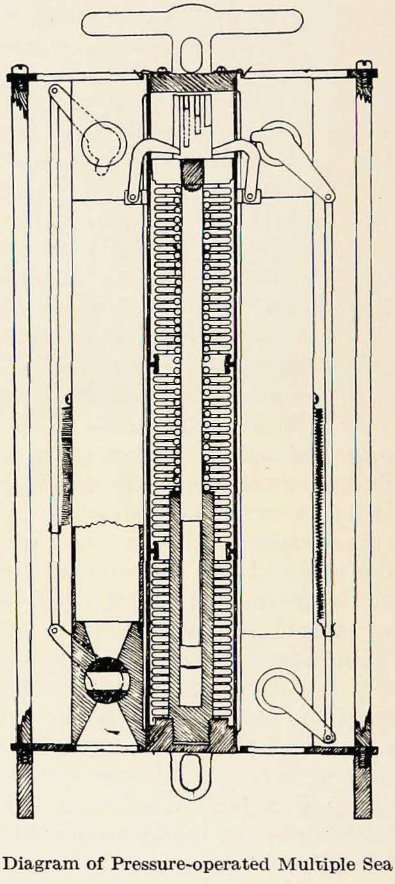

Figure 9. Diagram of Pressure-operated Multiple Sea Sampler.

A diagram showing the mechanism of the instrument is given in Figure 9 and a photograph of the completed instrument together with its carrying case and with two of the water bottles removed, is reproduced in Figure 10. Examination of these figures will show that essentially the instrument consists of a pressure responsive unit exactly similar to that used in the Bathythermograph which carries on its moving end a release controller which consists of a barrel with slots cut parallel to its axis. These slots are of different lengths and thus the trigger which presses on the barrel for each water bottle reaches the slot at a different pressure. Thus, each water bottle is released at a pressure which is determined by the length of the slot. Actually, in the instrument as built by the Submarine Signal Company, the release controller is so constructed that the triggering points of the different bottles may be varied at will, so that a distribution of depths for the six water bottles may be chosen according to the particular data required in each case.

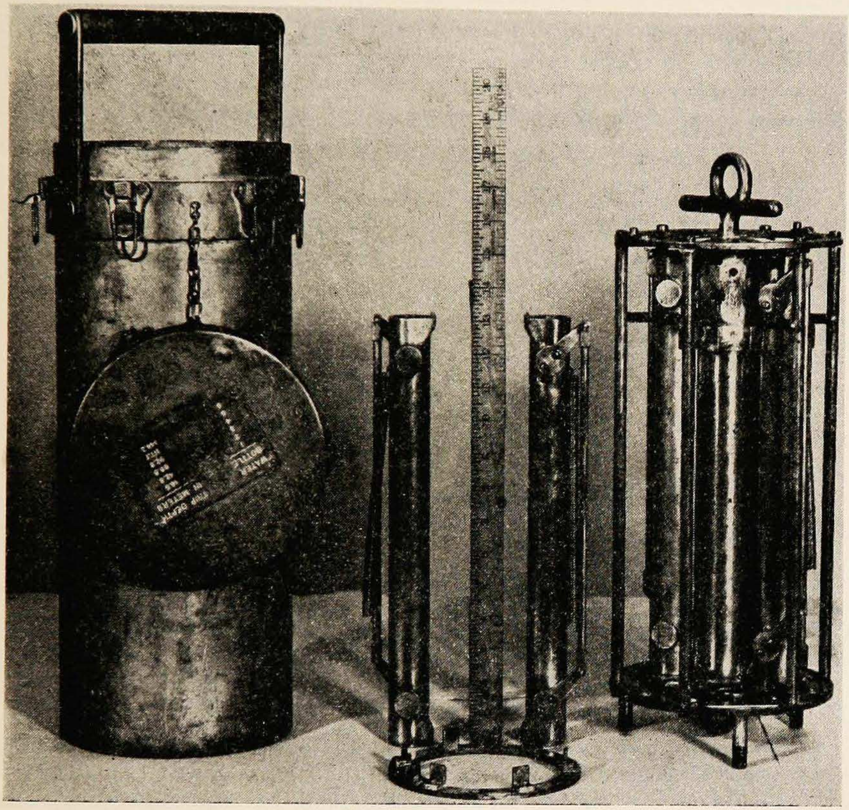

Figure 10. The Pressure-operated Multiple Sea Sampler, showing two of the water bottles removed, and the carrying case.

It should be possible to use the Pressure-operated Sea Sampler without stopping the vessel, although its bulk means that in all probability practical considerations will limit the speed of the vessel at which it can be lowered because its considerable drag will make it necessary to pay out a great length of wire in order to obtain the requisite depth. With the present Sea

Sampler, salinities have not been obtained while under way; however, this will be attempted directly the "Atlantis" is equipped with a hydrographic winch wire of sufficient strength so that there will be no danger of losing the instrument. In view of the fact that only one experimental model has been made, it has not been deemed advisable to risk the instrument on the regular hydrographic wire while the vessel is moving until a spare Sampler is available.

A considerable number of tests have been made with the Sea Sampler and these in general show slight differences in the Sea Sampler salinities from those obtained by the regular Nansen bottle technique. However, in many cases the differences may not immediately be ascribed to improper functioning of the Sampler, as it is extremely difficult to insure that the Nansen bottle trips at exactly the depth for which the Sea Sampler is set and it is, furthermore, extremely difficult to arrange that the two instruments take their samples at exactly the same time. Therefore, the differences observed in the tests may be due to the fact that the samples taken with the Nansen bottle were either taken not at the same depth or not at the same time, and both these factors may easily introduce real differences in the salinities of the order of magnitude found in the tests. In view of the fact that the Sampler is designed for use in the surface layers of the ocean where the salinity

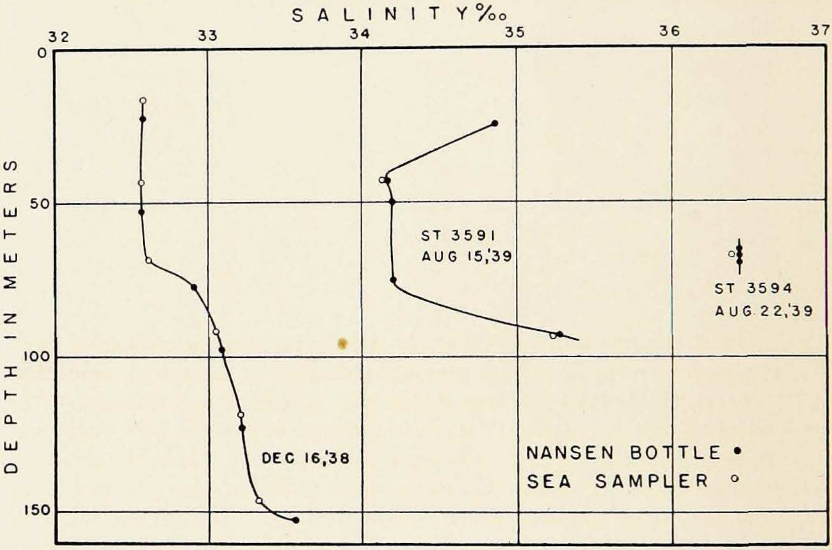

Figure 11. Comparisons between salinities obtained from Nansen Bottle samples and Sea Sampler specimens.

variations are considerable, greater errors in the salinities can be tolerated than would be possible at greater depths. Figure 11 shows curves of salinity against depth for some of the comparisons made at various times. While the differences indicated are not smaller than the usually recognized allowable error, they are small enough so that pending further development of the Sampler the instrument is useful.

Tests made in the laboratory to determine the triggering points of the various sample bottles reveal a high degree of accuracy as far as the repetition of the release pressure is concerned. The following figures were obtained in the pressure chamber of the Submarine Signal Company:

Water Jar	*Release Pressure*	*Equiv. Depth*
1	24 lbs. per sq. in.	16.3 meters
2	63 lbs. per sq. in.	42.8 meters
3	101 lbs. per sq. in.	68.7 meters
4	135 lbs. per sq. in.	91.7 meters
5	174 lbs. per sq. in.	118.3 meters
6	215 lbs. per sq. in.	146.2 meters

Repetition of the test indicated that the release pressure never varied more than one pound from the release pressure indicated in the above table; that is, in general, the bottles will trip within plus or minus half a meter of the predetermined depth. Tests at sea in conditions where the wire angle was entirely negligible also revealed a tripping accuracy well within the accuracy of the meter wheel. It is for this reason that confidence may be placed on the fundamental principle of the Pressure-operated Sea Sampler but it is realized that further development is required. Particularly is investigation required of the degree to which throttling at the stopcocks of the sample bottles is effective in slowing up the exchange of water within the bottles and thereby causing a lag effect on the indicated salinities. For the purpose of studying this throttling effect, two small water bottles were constructed such that the body of the bottles was of the same cross section as the opening in the stopcock. It was thought that this would reduce the throttling effect. It is surprising, however, to note that all samples obtained by means of these smaller bottles were in far greater error than those obtained with the large bottles, and this would indicate that the erroneous readings are due to contamination of the sample rather than the throttling effect, because such contamination, whether it be due to leakage at the stopcocks or the introduction of water of different salinity by some other means, will have a greater effect the smaller the sample taken.

RESULTS OF TWO CRUISES WITH THE RAPID MEASURING HYDROGRAPHIC INSTRUMENTS

During the summer of 1939 two cruises of the "Atlantis" were carried out on which the instruments described above were used. On the first cruise in July, the Sea Sampler did not operate with sufficient regularity to permit it to be used for actually obtaining useful data. The functioning was impaired by the fact that spring tension to bring the trigger out again after its depression into the release controller was insufficient and on most bottles the triggers were thus broken off during the ascent of the Sampler. As no facilities for the repairing of these triggers were available on board the instrument could not be used on the remainder of the cruise.

The Bathythermograph operated extremely satisfactorily and a continuous section for a distance of 175 miles was made with a single break of 30 miles in which no records were taken. During this stretch of 175 miles, 51 records were taken, that is, with the exception of the 30 mile break, a record on an average for every three miles. Most of the time during this section the "Atlantis" was travelling at a speed of about 7 knots, although on certain occasions the speed increased to as high as 11 knots. No trouble was experienced in using the Bathythermograph at such increased speeds beyond the necessity of paying out more wire in order to counteract the increase of wire angle. The procedure adopted in working a continuous section with the Bathythermograph is to lower the weight, about 120 lbs. of lead, into the water and keep it in the water, then to attach the Bathythermograph to the hydrographic wire at deck level so that the insertion and removal of slides may be accomplished without removing the instrument from the wire. After the slide is inserted the Bathythermograph is lowered at full speed into the water. Approximately 400 meters of wire must be paid out in order that the instrument may descend to 120 meters depth when the vessel is travelling at 7 knots.

The course of both cruises on which the Bathythermograph was used is shown on Figure 12. The line entered between Atlantis station No. 3562 and continuing beyond Atlantis station No. 3565, indicates the position of the first Bathythermograph section. The continuous section is represented in Figure 13 in the form of a diagram showing the isotherms down to a depth of 120 meters for a portion of this course.* Only 60 miles of the section is shown in Figure 13. The remaining parts of the section indicated a very regular horizontal distribution of the isotherms in both the tests made before Station 6 and those made after Station 28, so that they have not been included in the figure. The distribution of the isotherms, however, in Figure 13 reveals features of extreme interest; the boundary of the Gulf Stream proper is situated approximately at Station 11 on this diagram and

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* c. f. Fig. 12 for position of the portion of the course analyzed in Fig. 13.

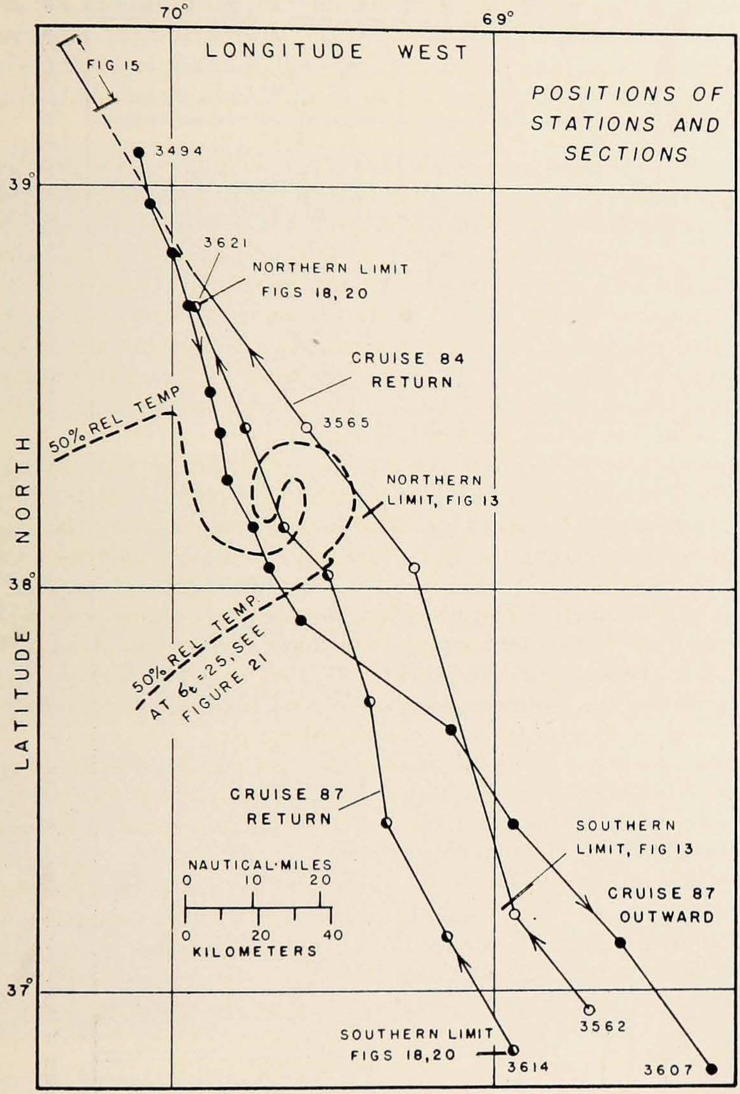

Figure 12. Chart showing positions of stations and sections. On the return route of cruise 84, full line indicates continuous Bathythermograph operation. Routine hydrographic stations marked by open circles. On the outward route of cruise 87 only routine hydrographic stations were made, as indicated by black dots. On the return route of cruise 87, full line indicates continuous operation of Bathythermograph, with Multiple Sea Sampler stations shown by black and white semicircles. Broken line indicates approximate course of 50% relative temperature boundary as shown in Figure 21.

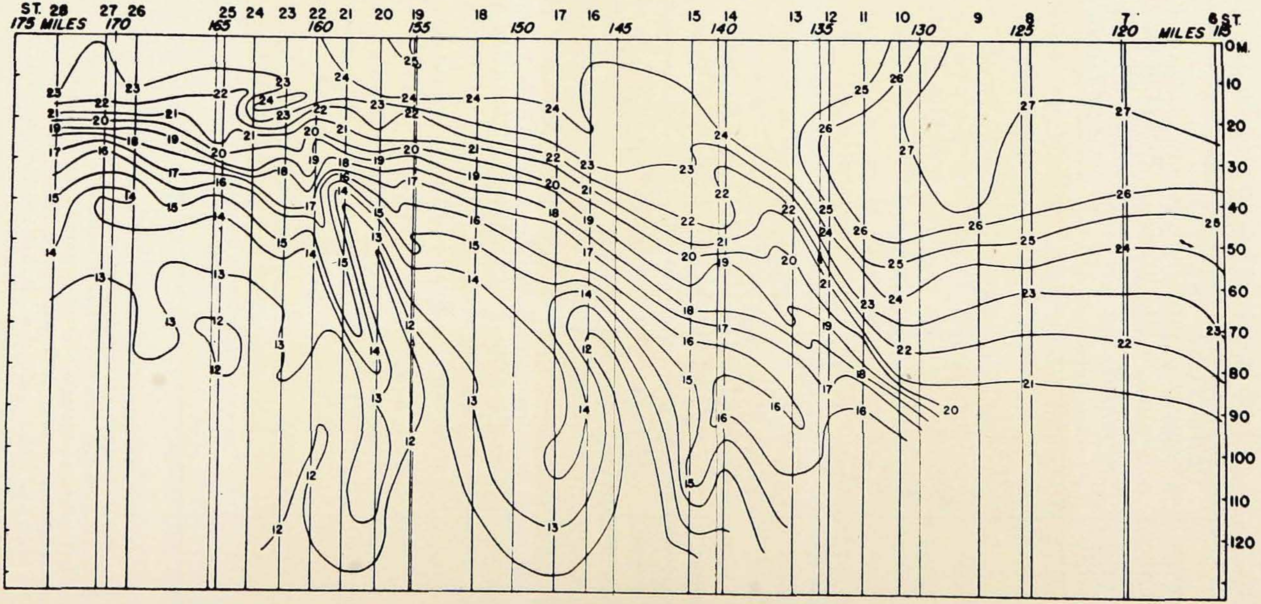

Figure 13. Distribution of isotherms in the surface layer in the neighborhood of the northwestern edge of the Gulf Stream (Cruise No. 84, July 1939).

it is in the water to the left of this point (looking down stream) that the isotherms are most disturbed. The 14° isotherm, for instance, exhibits in a 12 mile horizontal distance, between Stations 16 and 21, a variation from a depth of 65 meters at Station 16 to 110 meters at Station 17 and rising

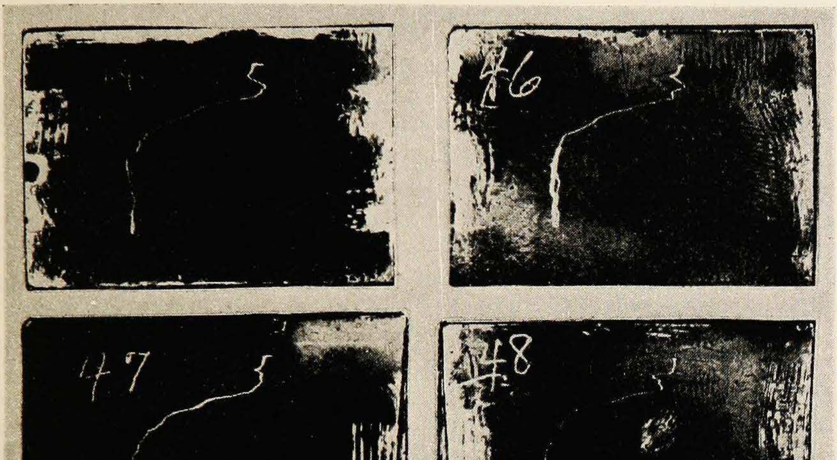

Figure 14. Some of the original records from which the data for figure 15 were obtained.

to a depth of only 40 meters in Station 21. These perturbations suggest the presence of a small eddy of the order of magnitude of 10 to 15 miles in size. Furthermore, from a knowledge of the general configuration of the isopycnals in these layers at the edge of the stream as given, for instance, in Figure 26 of Iselin's "Study of the Circulation of the Western North Atlantic," (Iselin 1936) it would seem that the shallower points of the 14° isotherm would lie along one ispycnal while the deeper points would fall along a different isopycnal, indicating that the water at the various shallower points was of the same origin (slope water) and that of the various deeper points of a different origin (Gulf Stream water). Because no salinities were taken simultaneously with the Bathythermograph soundings, it is not possible to

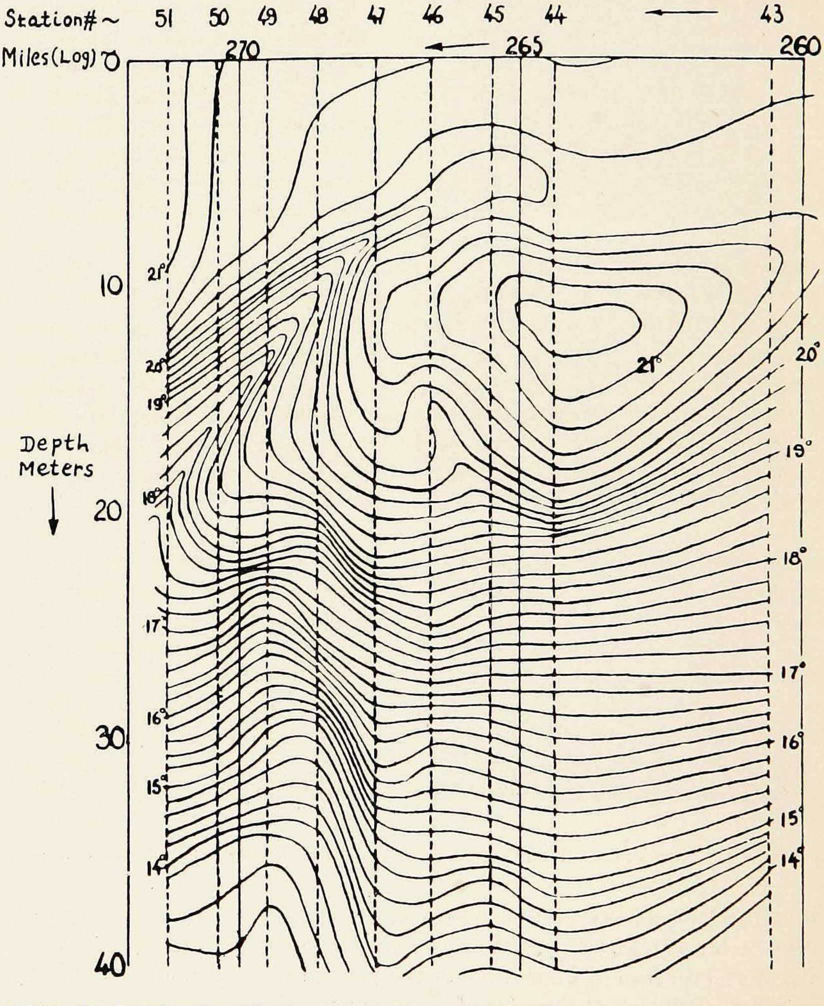

Figure 15. Distribution of isotherms in a short section (see Fig. 12), showing in detail the structure of a discontinuity zone in the surface layers.

establish the positions of the isopycnals in this particular case. On the second cruise densities were taken with the Sea Sampler and the above conclusion was ratified. This will be shown later.

A small section extending for a distance of 10 miles was made 30 miles to the north-west of the end of the continuous Bathythermograph section described above; the position of this section is shown in Figure 12 starting at Long. W. 70° 15′ and Lat. N. 39° 15′ approximately, and in this case Bathythermograph slide, No. 43, indicated a surface inversion of temperature starting at a depth of approximately 10 meters the highest temperature being recorded at about 13 meters. Similar surface inversions have been observed before, but not adequately explained. Therefore, directly this inversion was noted the Bathythermograph was operated rapidly and continuously so that for a 7 mile stretch records were obtained at intervals of less than a mile. Thus a very detailed analysis of this surface inversion could be made. The records are reproduced in their original form in Figure 14 and the inversion under scrutiny is that which occurs in the layer immediately over the summer thermocline. The nature of the inversion becomes clear when a detailed diagram of the isotherms in the first 40 meters is plotted. This diagram is shown in Figure 15, and it is likely that the inversion marks a sloping zone of discontinuity between the two water masses of slightly different characteristics. If, as is probable, although it cannot be proved in the present case as no salinities were taken, the sloping zone of discontinuity is bounded by surfaces of constant density, then Figure 15 provides an interesting pictorial representation of a "Margules slope" in the ocean.

Results of the Second Cruise.—After the Sea Sampler had been repaired and improvements incorporated to ensure its satisfactory operation, a second cruise was undertaken on the "Atlantis" with these instruments in August, 1939. The routine part of the cruise was to make one of the regular Gulf Stream sections as part of the Woods Hole program in connection with the Gulf Stream investigation. It was arranged, however, that on the return course of the vessel no stops would be made so that a continuous semi-synchronous section could be obtained with the Bathythermograph once more. Furthermore, provision was made to take water samples with the Pressure-operated Multiple Sea Sampler at intervals spaced further apart than the Bathythermograph stations but nevertheless close enough so that the distribution of isopycnals could be obtained. In Figure 12 the course of the second cruise is shown, and it is seen that the section is not far removed from the previous one and so it was to be expected that, if the small scale eddy observed at the edge of the Gulf Stream on the previous cruise and indicated by the disturbance of the isotherms in Figure 13 were real, it would be repeated in this case.

Figure 16 shows a plot of the isotherms for the cross section made by

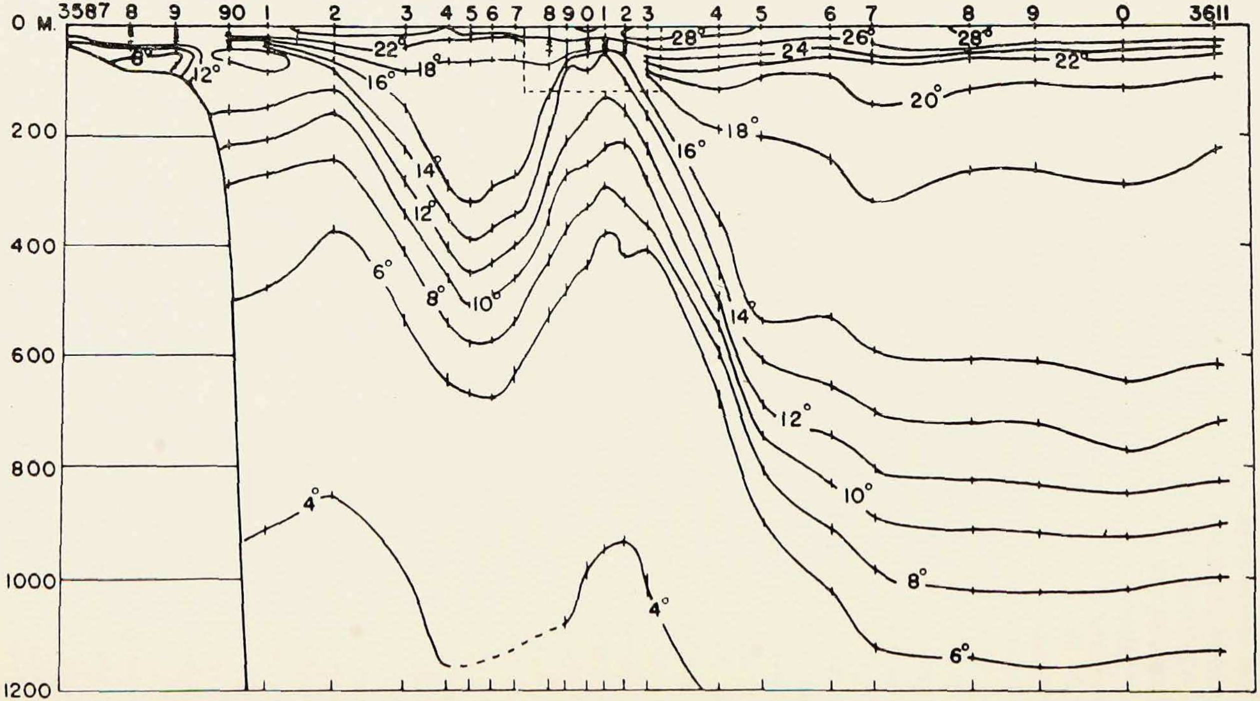

Figure 16. Distribution of the isotherms as determined by reversing thermometers on the Montauk Point to Bermuda section. Relative position of Bathythermograph section given in Figure 17 shown by rectangle in broken lines between stations 3597 and 3604 (Cruise No. 87, August 1939).

means of the regular hydrographic technique on the outgoing course of the vessel. An extremely well developed, large eddy is present on this occasion and this would imply that there is a high rate of shear and therefore an even better chance for the development of small scale eddies in the neighborhood of the edge of the Stream. The position of the Bathythermograph section is indicated by the dotted rectangle extending horizontally from station 3597 past station 3603 and down to a depth of approximately 120 meters. This section is shown in the detail revealed by the Bathythermograph analysis made on the return in Figure 17, and a similar temperature structure to that obtained in the previous Bathythermograph section is again found. Furthermore, just as in the case of the section shown in Figure 13, the shallower positions of any one isotherm appear to lie along a line which would correspond to an isopycnal and the deeper positions along another ispycnal. However, in this case, with the aid of the salinities obtained by the Pressure-operated Multiple Sea Sampler, the actual isopycnals may be plotted and these are shown in Figure 18.

The distribution of the isopycnals obtained by the new rapid measuring instruments and shown in Figure 18, may be compared with those obtained on the outgoing section by the regular hydrographic technique and shown in Figure 19. The general configuration of the isopycnals is identical although the absolute depth at which any one density occurs is not the same on the two occasions. It is entirely possible that such changes could occur in the intervening few days between the outgoing stations in this region and the incoming ones.

The spacing of the stations at which samples were taken for salinity determinations and, therefore, for which the depth of the isopycnals may be computed was not as close as the spacing of the Bathythermograph stations. It therefore might seem that in drawing the course of the isopycnals in Figure 18 and also in Figure 19, the latter from densities obtained by the regular hydrographic technique, considerable smoothing has been carried out and that actually the isopycnals may wander in between the points at which salinity was determined. Unless very short intervals are made between the Sea Sampler stations, no definite evidence to prove conclusively that the isopycnals do not wander can be obtained. In a recent study (Seiwell 1939) the assumption has been made that the changes in depths of the isotherms are entirely due to changes in depth of the isopycnals, where here the assumption made is exactly the reverse, in other words, that changes in depth of the isotherms are due entirely to changes in the temperature salinity correlation. It is probable that neither of these extremes is entirely permissible. Seiwell's analysis, however, was for much deeper layers than the present one and indirect evidence in our case would indicate that the assumption made here is valid. For instance, the comparison of Figure 18 with Figure 19 which reveals an identical general configuration of the iso-

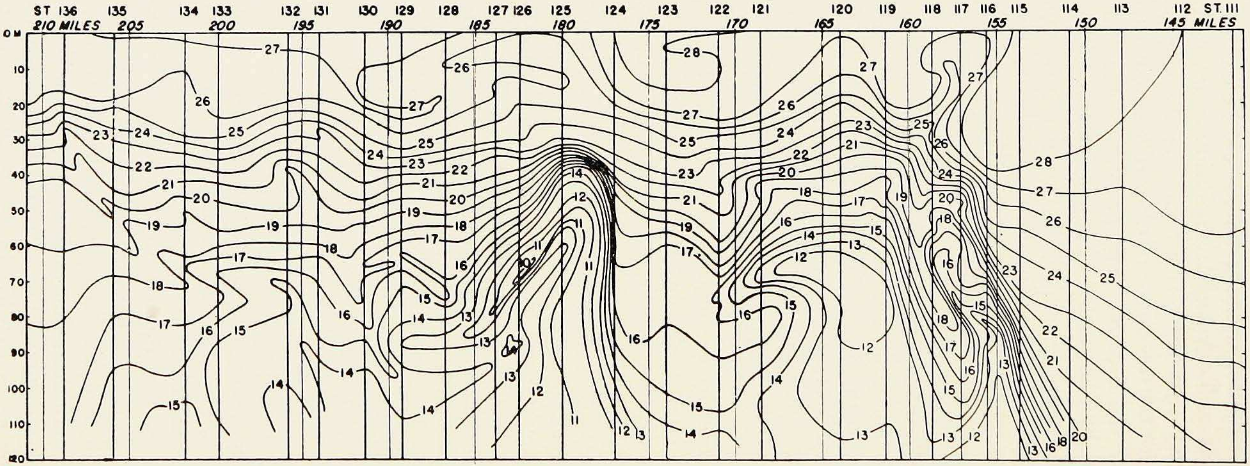

Figure 17. Distribution of isotherms in the surface layers in the neighborhood of the northwestern edge of the Gulf Stream as shown by Bathythermograph records (Cruise No. 87, August 1939).

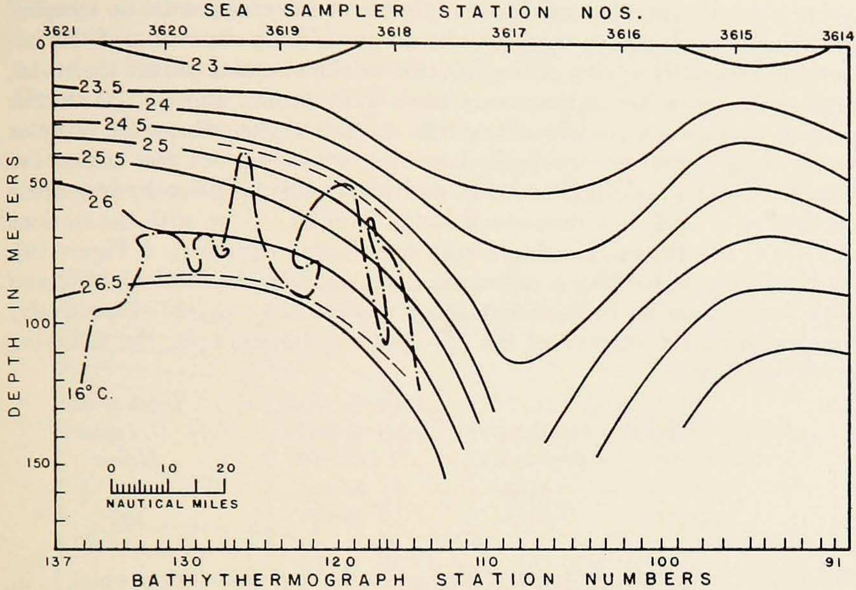

Figure 18. Distribution of isopycnals and 16° isotherm from Bathythermograph and Sea Sampler data.

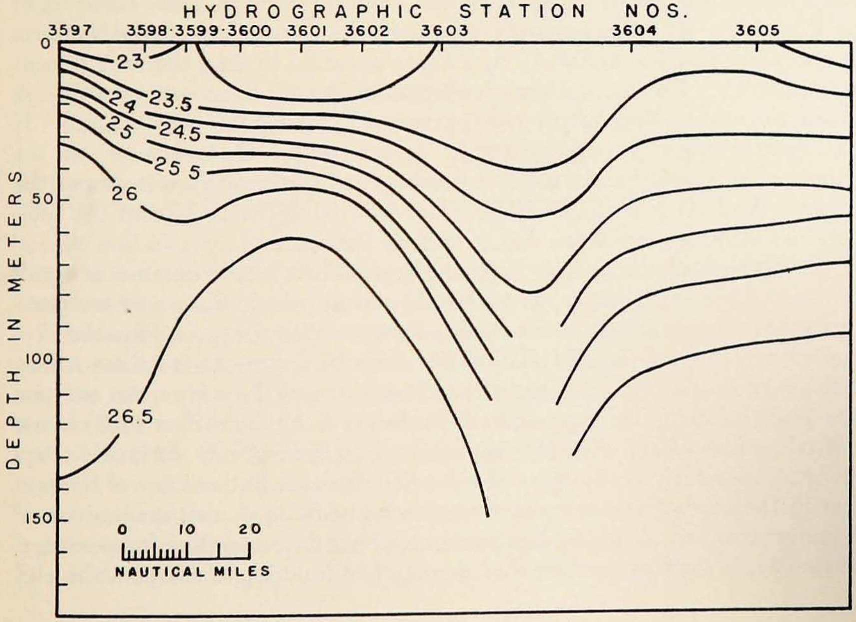

Figure 19. Distribution of isopycnals according to observations from routine hydrographic stations.

pycnals on the outgoing and incoming parts of the cruise must be accepted as rather good evidence that there is no small scale distortion of the isopycnals, especially in view of the fact that on the outgoing part of the cruise, regular hydrographic stations were made at extremely short intervals; the part of this section, which corresponds to that region where the complex temperature structure is observed on the return part of the cruise, lies between "Atlantis" stations 3598 and 3603 and here six hydrographic stations were made in a distance of about 50 miles. Even with the stations as close as this the isopycnals are very smooth and regular (c. f. Figure 19). Furthermore, if the data is examined from sea sampler stations 3618 and 3619 (corresponding Bathythermograph station 116 and 123 respectively) by comparing the salinity at the 15° Isotherm for example, the following result is found:—

Bathythermograph Station No.	*Sea Sampler Station No.*	*Salinity °/₀₀ at the Depth of the 15° C. Isotherm*	*Depth of the 15° C. Isotherm Meters*
116	3618	34.60	77
123	3619	35.97	102

This shows an extremely marked change in the T-S correlation which is in agreement with our assumption of a relatively smooth distribution of density.

In order to test the suggestion made above regarding the relation of the isotherms to the isopycnal surfaces the 16° isotherm has been sketched in on Figure 19. It is immediately seen that the wanderings of the isotherm in the vertical occur definitely in a layer enclosed by two surfaces of constant density. The 16° isotherm is chosen arbitrarily as an example, though others for other values of the temperature will reveal the same feature. It has been frequently emphasized in oceanography that reliance on the temperature salinity correlation is not justified in the surface layers of the ocean. While it is quite true that there will be departures from the temperature salinity correlation due to surface heating and evaporation effects, in the opinion of the author it is in all probability the presence of small eddies and the consequent lateral mixing which principally upset temperature salinity correlations in the surface layers. Therefore, a method involving temperature salinity correlation will reveal the presence of these eddies if the station spacing is less than the dimensions of the eddy. An analysis was made following the suggestion of Professor A. E. Parr (Parr 1938) to use relative values of the identifying property along isopycnal surfaces. Parr chose to use relative salinity as his identifying value but in view of the fact that in the case of the new rapid measuring technique continuous records of temperature are available it is preferable here to use relative temperature. Obviously, in view of the fact that density is a function of temperature and salinity, either temperature or salinity on an isopycnal is perfectly suitable for such identification. Therefore, values of the relative temperature obtained in exactly the manner outlined by Parr were worked out and in Figure 20 iso-lines of the 50% relative temperature values have been drawn. These give an indication of the division of the tongues of slope water and tongues of Gulf Stream water, the former with relative temperatures less than 50%, the latter greater than 50%. The figure shows in a very remarkable fashion that the intrusion of slope water is in the form of a tongue which extends to depths without much lateral displacement.

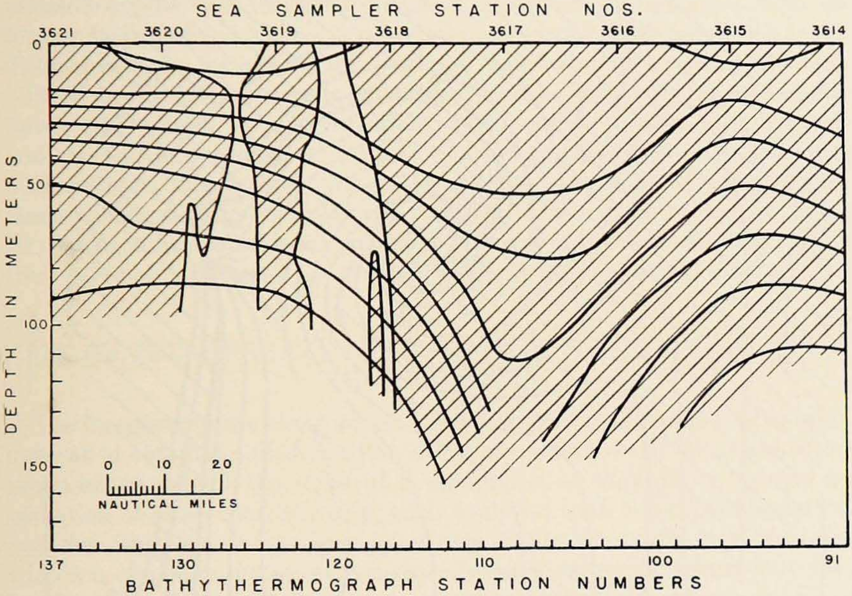

Figure 20. Distribution of relative temperatures in section shown in Figure 18. Relative temperatures above 50% indicated by hatched areas, below 50% by blank regions.

While explicit conclusions regarding the nature of the eddy (its direction and rotation etc.), which in cross section would give this distribution of relative temperatures, may not be drawn from a single section, it may be shown that a formalized and entirely logical eddy formation will fit the available data. Thus in Figure 21 the temperatures along the surface of $\sigma_T = 25$ are plotted, and a series of isotherms, representing a reasonable eddy formation, are drawn in which satisfy the data. An extremely interesting feature on this diagram is the appearance of a parasite eddy on the right side of the cold tongue. This parasite eddy was indicated on the cross section on Figure 20. Referring to this figure, it will be seen that there is at Station 117 a small intrusion in warm water for which the 50% relative temperature extends to a depth of 85 meters. Furthermore, on Figure 20 there appears to be a second parasite eddy at Station 129. This second parasite on the left side of the cold tongue is not shown up on the surface of $\sigma_T = 25$ but it appears on a similar diagram for $\sigma_T = 26$. Perhaps the appearance of these parasite eddies is one of the most interesting features brought out by this analysis. While they are in no sense incontrovertibly established by the present data and must to a large extent be regarded as speculation on the part of the writer, it is believed that they must exist in

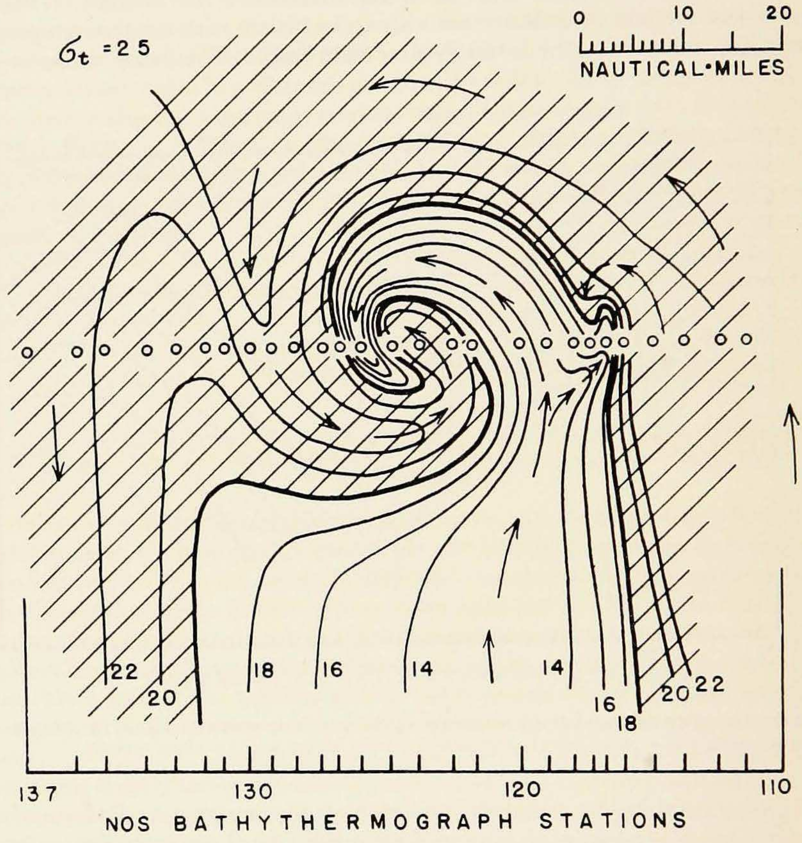

Figure 21. Eddy of intermediate size with parasite drawn to conform with temperature distribution on the isopycnal surface of $\sigma_T = 25$ (somewhat diagrammatical).

any such eddy formation. Also, the data, such as it is, lends support to the belief in their existence. In all probability, many more parasite eddies would be found on the tongue if a great number of sections were taken so that a well distributed field of temperatures could be plotted on the surface.

It is interesting to observe that in this particular case we have quite clear indications of three distinctly different sizes of eddies. First, the large scale eddy which is shown up by the distortion of the isotherms down to considerable depths as indicated in Figure 16. By the data obtained with the routine hydrographic technique the dimension of this eddy measured as the distance between the axes of the dissimilar tongues, is of the order of magnitude of about 150 kilometers. Secondly, we have the intermediate eddy shown on Figure 21 with a corresponding dimension of about 30 kilometers and, thirdly, the parasite eddies with a dimension of the order of magnitude of 5 kilometers. The intermediate size is of the same order of magnitude as Dr. Rossby's estimate on the basis of a shear of 10^{-5} sec.$^{-1}$ (Rossby 1938), and this would indicate that eddies of these dimensions are numerous enough for their effect on large scale phenomena to be capable of statistical treatment.

PROJECTED OPERATIONS WITH THE RAPID MEASURING INSTRUMENTS

The foregoing preliminary analysis has demonstrated that it is of extreme interest to obtain detailed analyses of the surface layers of the ocean. It is proposed to extend this type of investigation so that either by the cooperation of more than one ship, each equipped with a Bathythermograph and Sea Sampler, or by zig-zagging over the region to be studied, a distribution of points in the isopycnal surface taken semi-synchronously may be obtained. This will enable confirmation of the eddy patterns outlined above to be obtained by an analysis of the type employed by Montgomery (1938).

It is further proposed that after development of the individual mechanisms of the Bathythermograph and Sea Sampler is progressed to a satisfactory point they may be combined such that the same pressure element will be used to trip the Sea Sampler water bottles and also to carry the slide of the Bathythermograph unit. The desirability of making temperature and salinity measurements at exactly the same point even though the position of this point is not so accurately known, has been stressed by Dr. Montgomery and such a combination of the two instruments will insure that the temperature at which salinity sample was taken is accurately known. The proposed combination is illustrated in the diagram Figure 22. It is believed that when each water bottle trips there will be a sufficient jar to the instrument so that the recording stylus of the thermal unit will make

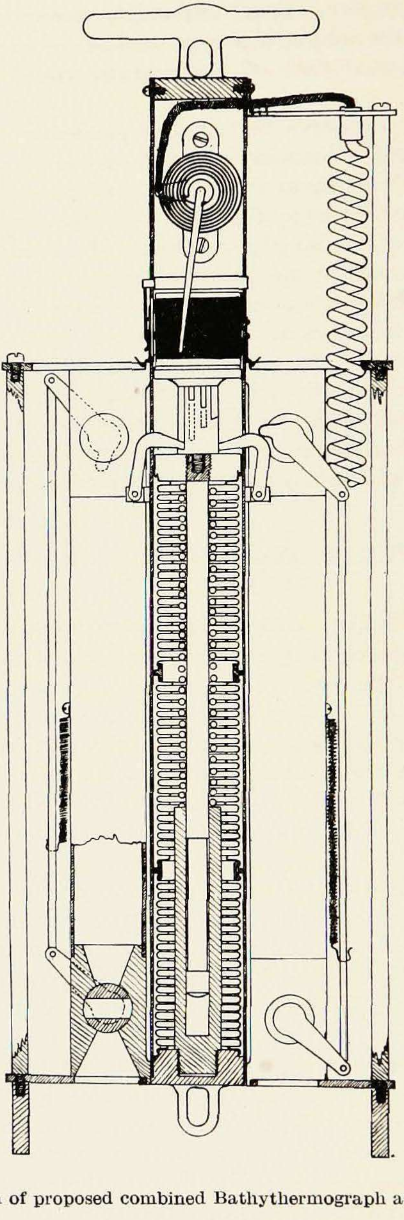

Figure 22. Diagram of proposed combined Bathythermograph and Pressure-operated Sea Sampler.

a noticeable mark on the temperature depth trace. This will be valuable, in addition, for establishing exactly the point of tripping. If it is found that jar caused by the water bottle tripping is insufficient to make such a mark, a simple mechanism is contemplated which will accomplish this.

Such investigations as these, where a complete change in the characteristics of the water may be expected to take place within a distance of a few miles, necessitate fixing the relative positions of the Bathythermograph stations very exactly. In the case of the data described above, the sections plotted for the Bathythermograph are plotted on a horizontal scale representing the reading of the ship's log, that is the distance relative to the water. However, if more than one section is taken the relative positions of the different sections will have to be obtained exactly. If more than one vessel is employed, range finders to obtain relative positions would be very valuable.

In conclusion the writer wishes to express his indebtedness to the Submarine Signal Company of Boston, Massachusetts, who undertook the construction of the instruments described above and without whose assistance the investigation would hardly have been possible.

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