PAPERS IN PHYSICAL OCEANOGRAPHY AND METEOROLOGY
Published by
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
and
WOODS HOLE OCEANOGRAPHIC INSTITUTION
(In continuation of Massachusetts Institute of Technology Meteorological Papers)

VOL. II, NO. 1

SCIENTIFIC RESULTS OF THE "NAUTILUS" EXPEDITION, 1931

Under the Command of Capt. Sir Hubert Wilkins

Parts I to III

BY
H. U. SVERDRUP
and
F. M. SOULE

CAMBRIDGE, MASSACHUSETTS
March, 1933

CONTENTS

SCIENTIFIC RESULTS OF THE "NAUTILUS" EXPEDITION, 1931, UNDER THE COMMAND OF CAPTAIN SIR HUBERT WILKINS. PARTS I TO III.

I. INTRODUCTION AND NARRATIVE

By H. U. SVERDRUP
Leader of the Scientific Staff

Contribution No. 1 from the Woods Hole Oceanographic Institution

Introduction

In 1930 Sir Hubert Wilkins announced his plan for exploring the Polar Sea by submarine. Thanks to the courtesy of the U. S. Navy Department and the U. S. Shipping Board the submarine O 12 was placed at his disposal and the constructor of this vessel, Mr. Simon Lake, undertook to rebuild it and make it suitable for travelling underneath the Arctic pack-ice. After rebuilding the submarine was in the spring of 1931 named *Nautilus*.

The scientific work of the expedition should be conducted by the writer, who proposed a program which briefly can be outlined as follows:

A. *Observations at Stations, Supposing These to be Occupied at Intervals of about 50 Miles*

1. Observations for positions.

2. Magnetic observations comprising inclination and total intensity and, if possible, declination. These observations should be taken on the ice at a distance of not less than 70 meters, preferably 100 meters, from the ship.

3. Oceanographic observations. At every third station temperatures and water samples from the surface to the bottom. Assuming the depth to be about 4000 meters, three hauls would be necessary, Series I comprising depths: near the bottom, 3500, 3000, 2500 and 2000; Series II comprising depths: 1800, 1600, 1400, 1200, 1000, 800, 600, 500 and 400; Series III comprising depths: 300, 200, 150, 100, 75, 50, 40, 30 and 5 meters. The sets of observations were taken in the following alternation:—A, Oceanographic Series II and III and bottom sample; B, Oceanographic Series II and III and vertical hauls with closing nets in order to collect biological material; C, Oceanographic Series I, II and III.

4. Meteorological observations, comprising barometric pressure, air temperature and humidity, direction and velocity of wind, cloudiness, cloud forms and weather.

5. Chemical investigation of the sea-water samples to the extent which time permitted.

6. Reception of rhythmic time signals for control of the chronometers of the gravity apparatus.

B. *Observations When Under Way*

1. Depths by sonic depth-finder every three or four miles.

2. Spectrographic investigations of the light penetrating through the sea water and the ice, to be undertaken at different depths when the submarine was diving and preferably at a constant depth when under way.

3. Collection of biological material by means of Dr. Hardy's continuous plankton recorder.

4. Gravity observations with the Vening Meinesz apparatus.

5. Chemical investigation of the sea-water samples.

In order to carry this program out the party of the expedition should include two scientists besides the writer.

The Carnegie Institution of Washington promised to co-operate with the expedition through its Department of Terrestrial Magnetism, which assigned one of their scientists, Mr. Floyd M. Soule, to the expedition as magnetician and oceanographic assistant. Mr. Soule had taken part in the seventh cruise of the *Carnegie* and had from that cruise extensive experience as to echo-soundings and collection of deep-sea water samples. The Department also placed all necessary magnetic instruments at the disposal of the expedition. The co-operation of the Carnegie Institution and the assignment of an experienced and able scientist was of invaluable importance to the scientific work of the expedition.

As to the third scientist, Wilkins left the choice in my hands and I was fortunate enough to secure the assistance of Dr. B. Villinger of Freiburg i. Br. who was to serve as the physician of the expedition, have charge of the gravity observations and help in part of the chemical oceanographic work. Dr. Villinger, who knew arctic conditions from expeditions to Spitsbergen and Greenland, had a wide and varied experience as physician and considerable practice in research work, was very well qualified for taking part in an expedition such as the present.

The Woods Hole Oceanographic Institution contributed a sum which should be used for adequate scientific equipment and expenses in connection with the scientific work. Thanks to this generous contribution Wilkins could place the necessary funds at my disposal and we were able to obtain the best and most modern instruments.

Dr. A. C. Hardy of University College, Hull, furthermore supplied the expedition with one of his continuous plankton recorders.

The instruments for the different investigations will be described in the special reports, dealing with the results within the different fields. In this place it shall only be mentioned that the deep-sea oceanographic observations were to be taken in a diving chamber which had been arranged in the foremost compartment of the vessel. The diving compartment was connected by an air lock with the compartment of the leader of the expedition and the scientists. When the doors had been closed, compressed air could be led into the diving compartment and the air pressure in the compartment could be increased until it balanced the pressure of the water against the bottom of the ship. When this had been accomplished a trap door in the bottom of the compartment could be opened without the water entering the room and the wire to which the deep-sea instruments were attached could be lowered. Thanks to this arrangement it was possible to obtain deep-sea observations even if the submarine did not reach the surface and one could work in a closed room, protected against wind and weather and more conveniently than is possible on the narrow deck of the ship. A hydrographic winch, to be driven by a motor in the central control compartment, from which an axis led forward, was installed in the compartment.

All instruments for navigation were acquired before the departure of the submarine from the United States and in addition the sonic depth-finder and the hydrographic winch were installed, while the other scientific instruments were sent to Bergen to be brought onboard the *Nautilus* on her arrival there, which according to the original plans should take place at the end of May. The two other scientific members of the expedition both arrived in Bergen at the beginning of May in order to get familiar with the chemical oceanographic work in which they were to take part, Mr. Soule bringing with him the complete set of magnetic instruments which the Carnegie Institution had placed at the disposal of the expedition.

Dr. Villinger had spent two weeks of April with Dr. Vening-Meinesz and familiarized himself with the handling of the delicate gravity apparatus and the reception of the rhythmic time signals, upon which the rate of the chronometers has to be based.

The time for the joint preparations became more than ample. The departure of the *Nautilus* from the United States was delayed until June 4, and after the unfortunate crossing of the Atlantic the ship had to undergo repairs and changes at Devenport, England, which caused a further delay of more than three weeks, and instead of arriving in Bergen at the end of May, the *Nautilus* came on August 1.

Dr. Vening-Meinesz had hoped personally to supervise the mounting of the gravity apparatus onboard the *Nautilus*, but because of other duties he could not postpone his visit to Bergen indefinitely. He, therefore, arrived the middle of July, bringing with him the pendulums for the gravity apparatus and a special third chronometer, while the two main chronometers already had been delivered personally by one of the directors of the firm Ulysse Nardin, Le Locle, Switzerland. After final adjustments, Dr. Vening-Meinesz and Dr. Villinger undertook a series of gravity observations in Bergen.

Mr. Soule had, besides making himself familiar with determination of the oxygen content of sea water and different phases of other chemical work, undertaken magnetic observations at Hop near Bergen and at the magnetic observatory at Dombaas and had compared his instruments with those of the Geophysical Institute in Bergen.

The time of waiting also had been used for distributing the scientific equipment in small suitable packing boxes which could be stowed away easily, making racks for the deep-sea water bottles, stands for glass bottles and in other ways preparing a rapid installment of the extensive scientific equipment.

It had been understood that the scientists, who were to join the expedition in Bergen, should be under no obligation to do so unless they were satisfied that the machinery of the submarine functioned properly and that all the special devices, which had been installed in order to overcome the difficulties of navigation under and in ice, had been thoroughly tested under conditions similar to those to be expected in the Polar Sea. Originally it had been planned to undertake such tests in the ice off the coast of Labrador, but the rebuilding of the ship had taken more time than anticipated and at the arrival in Bergen no special tests had been carried out. The machinery had been overhauled and improved in Devenport, but in spite of this was not in the state which should be demanded when starting out on a long expedition. On the other hand, the season was so far advanced that the original ambitious plan to cross the Polar Sea from Spitsbergen to Bering Strait could not be carried out and even an attempt to reach the North Pole by submarine could not be undertaken. The available time in the season of 1931 only permitted extensive trials in the area to the north and northwest of Spitsbergen, and perhaps a shorter cruise to the north under the ice. Since such trials and tests probably could be undertaken without any great risk, and since the region to the north and northwest of Spitsbergen in many respects was of the greatest interest to science, the scientists did not hesitate to join the expedition in spite of the probable deficiencies of the vessel.

The scientific instruments were taken onboard in Bergen and mounted or stowed away simultaneously with the loading of provisions and arctic equipment, and on August 5 the *Nautilus* proceeded from Bergen via Tromsø to Advent Bay in Spitsbergen.

The accompanying sketch (fig. 1) gives an idea of the arrangement in the crowded quarters which were available for the scientists and for the scientific work. The greatest disadvantage of the small rooms was that many instruments, which had to be used daily,

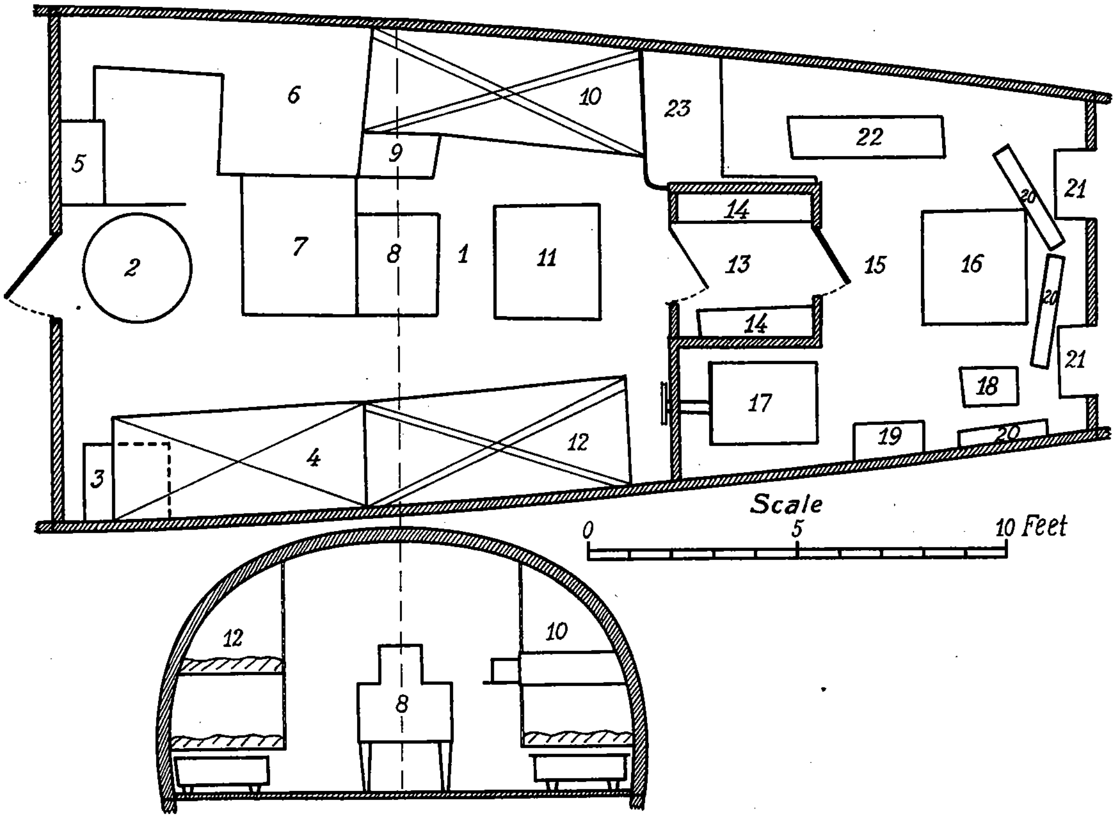

FIG. 1.—Plan of the compartment for the scientists, and of the diving compartment

1 Living room and laboratory.
2 Ice-drill.
3 Motor and winch for ice-drill.
4 Berth (Dr. Villinger). Boxes under berth for bottles with chemical solutions.
5 Sonic depth-finder.
6 Radio station.
7 Table for colorimeter and titration apparatus. Boxes under table with glassware and distilled water.
8 Gravity apparatus.
9 Shelf for chronometers.
10 Berths. (Sir Hubert Wilkins and Mr. R. Meyers, radio expert.)
11 Table built of boxes for water samples.
12 Berths. (Dr. Sverdrup and Mr. Soule.) Magnetic instruments under lower berth.
13 Air lock.
14 Boxes for water samples and bottom samples.
15 Diving compartment.
16 Diving hatch.
17 Hydrographic winch.
18 Pulley.
19 Boxes for water samples.
20 Racks for water bottles.
21 Torpedo tubes.
22 Bottom samplers.
23 Small air lock.

could not remain mounted but had to be taken down and stowed away each time. After some trials we were, however, able to adjust ourselves to the conditions and became less and less handicapped by the very limited space which was at our disposal.

We left Advent Bay in Spitsbergen on August 18 and on the 19th the northern coast of Spitsbergen disappeared on the southern horizon. We had two tasks before us: In the first place to test whether the submarine could navigate safely under the ice, whether the lanes and openings in the ice could be seen from underneath, and whether the submarine could reach the surface in such openings. In the second place, we had to learn whether our scientific program could be carried out under the unfavorable conditions onboard a submarine, and especially if the oceanographic work could be undertaken from the diving compartment.

The loss of the diving rudder which was discovered on August 22 made diving and travel under the ice impossible and, therefore, it remained to try out the scientific equipment and make such observations as conditions would permit. We were, however, much hampered in our scientific work by the circumstance that all instruments had been acquired and all plans laid with the conditions in the ice in view and that, therefore, we were unable to carry out any work unless we had the protection against the sea which the ice offers. In other words, we had to find scattered ice and to enter this in order to be able to carry out our scientific work. As to the magnetic work, it would be necessary to find ice-floes of such size that their motion was small.

A long-lasting storm from the east pressed the ice together and closed every opening; for days we had to wait outside of the pack-ice, hoping that the wind would fall, or change direction and that the ice-fields would open up. The storm, however, had not only packed the ice together, but had carried it towards the north and by following the boundary of the pack-ice we, therefore, reached a higher latitude than any other expedition vessel starting out from Spitsbergen, and could undertake our observations in unexplored regions.

During the night between August 25 and 26 the wind finally changed from E. to SSW. On the morning of the 26th a gentle breeze from SSW. was blowing and the swell was rapidly decreasing. A number (99) of soundings had been taken before August 26 by means of the sonic depth-finder under the supervision of Mr. Soule and rhythmic time signals for checking the rate of the chronometers of the gravity apparatus had been received twice daily by Dr. Villinger. Apart from this, no scientific observations had been carried out, except for a few meteorological observations which on account of their unsystematic and accidental character are of no value. The 11 days from August 26 to September 6 were, on the other hand, mainly devoted to scientific work and a brief account of our occupation during these days shall, therefore, be given. In this connection attention is drawn to the route of the expedition as shown on fig. 2. All hours given in the following are in G.M.T.

August 26. Work in the diving compartment between 11^h and $17^h\ 30^m$. Awaiting better conditions for work. Time signals received.

August 27. Observations of the sun for position at 6^h and 10^h. Work in the diving compartment from 8^h to $16^h\ 15^m$. Water bottles emptied and temperatures read between 17^h and 18^h, examination of water samples and correction of temperatures between $18^h\ 30^m$ and $22^h\ 30^m$. Under way towards the east between August 27, 19^h and August 28, 1^h. Echo-soundings Nos. 103 to 111. Time signals received.

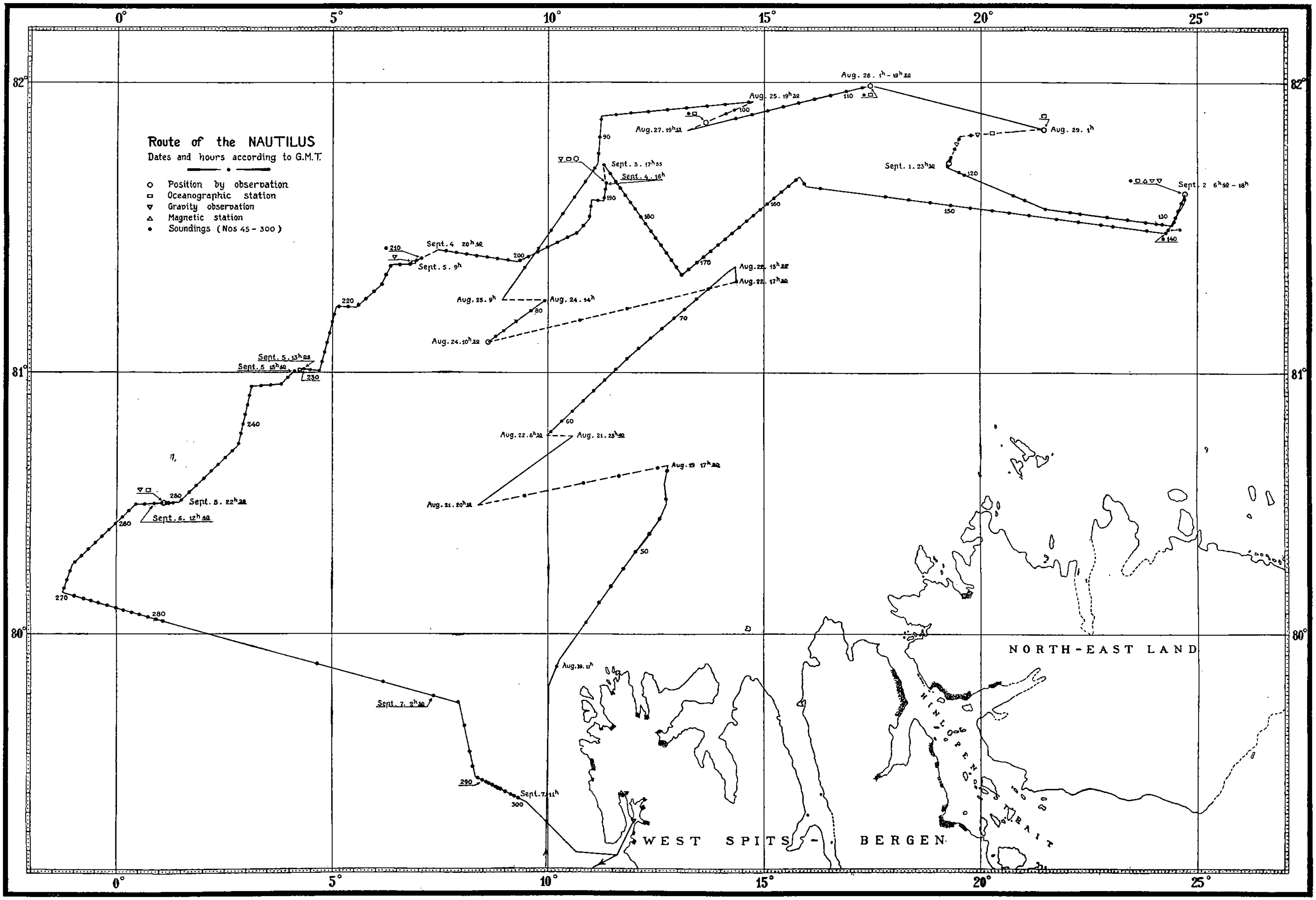

FIG. 2.—Chart of the route of the *Nautilus*

August 28. Observations of the sun for position at local noon and at 14^h 40^m. Work in the diving compartment from 8^h to 12^h. Water bottles emptied, thermometers read, water samples examined and temperatures corrected from 13^h to 20^h 30^m. In the afternoon birds collected. Under way towards the east from August 28, 19^h 20^m to August 29, 1^h. Sonic depth-finder failed to work because echo too weak to be heard when engines were running. Time signals received.

August 29. Observations of sun for position at 9^h and at local noon. Work in the diving compartment from 9^h to 11^h 15^m. Analysis of water samples and correction of temperatures, collection of birds from 14^h to 19^h. Fog prevents progress towards the east. Time signals received.

August 30. Fog still prevents progress towards the east. Oceanographic work from deck from 14^h to 16^h. Analysis of water samples and correction of temperatures from 16^h to 18^h. Gravity observation from 21^h 30^m to 22^h 30^m. Time signals received.

August 31. Gravity observation from 7^h 45^m to 8^h 45^m. Day used for attempts at pushing the *Nautilus* under the ice and trying the ice-drills.

September 1. Observations for position at 7^h 30^m, 10^h 50^m and 13^h 20^m. Intended to proceed towards the east in the early morning but had to stay because of trouble with the oil which had become too thick on account of the low temperature. In the afternoon when charging batteries, searched in vain for an ice-floe big enough for magnetic observations. Under way towards the east from September 1, 23^h 30^m to September 2, 6^h 40^m. Echo-soundings Nos. 119 to 133. Time signals received.

September 2. Observations of the sun for position by sextant at 6^h 40^m, and 12^h 00^m and by theodolite at 15^h 00^m. Work in the diving compartment from 7^h 30^m to 11^h 30^m, gravity observations from 8^h 30^m to 9^h 30^m and from 10^h 30^m to 11^h 30^m, alongside big floe from 14^h to 16^h, magnetic observation. Decided to turn back to the western area because shallow waters had been reached. Under way at 17^h 30^m, but stopped at 18^h 10^m in order to thaw out microphones of sonic depth-finder, which were frozen in. Under way again from September 2, 23^h to September 3, 18^h. Echo-soundings Nos. 137 to 187. Time signals received.

September 3. Under way. Computations and checkings. Time signals received.

September 4. Observations of the sun for position at 6^h 30^m, 8^h 50^m and 12^h. From 7^h to 11^h attempts at pushing the *Nautilus* under the ice, photographing. Work in the diving compartment from 12^h 15^m to 15^h, gravity observation from 13^h to 14^h, analysis of water samples and correction of temperatures from 16^h to 20^h. Under way towards SW from 16^h to 20^h 40^m, echo-soundings Nos. 189 to 208. Time signals received.

September 5. Work in the diving compartment from 4^h 30^m to 7^h 15^m, gravity observation from 7^h 15^m to 8^h 15^m, under way towards the southwest from 9^h to 13^h 05^m, echo-soundings Nos. 212 to 230, analysis of water samples, etc., from 9^h to 12^h. Work in the diving compartment from 13^h 15^m to 15^h 10^m, under way towards the southwest from 15^h 40^m to 22^h 25^m, echo-soundings Nos. 231 to 250, analysis of water samples, etc., from 16^h to 21^h. Time signals received.

September 6. Observations for position at $10^h\ 25^m$ and at $11^h\ 30^m$. Work in diving compartment from $7^h\ 30^m$ to $11^h\ 15^m$, gravity observation $11^h\ 30^m$ to $12^h\ 30^m$, under way towards the southwest from $12^h\ 40^m$ to $16^h\ 10^m$, echo-soundings Nos. 255 to 269. Wind increasing from NE, ice getting more and more tightly packed. Decided to return to Spitsbergen, course changed to easterly. September 6, after 17^h, and September 7, echo-soundings Nos. 270 to 300. Time signals received.

From this brief account it is seen that we were able to try out our scientific equipment, except the spectrograph, which was especially intended for use when submerged. The magnetic work, however, was very limited because the ice was so much torn to pieces that no big and quiet ice-floes could be found.

Fortunately we had several days with the sun visible part of the day and thus we obtained a sufficient number of observations for position to be able to determine our route with a considerable degree of accuracy in spite of the fact that the vessel occasionally drifted with the wind and the ice. The excellent patent log and the gyro compass, which functioned perfectly up to a latitude of 82° (taking the corrections which were supplied by the makers into account) proved to give a very reliable basis for computation of position by dead reckoning.

The different phases of the scientific work will be described in the special reports and here it is not necessary to enter upon them. In this place it shall only be remarked that our route as shown on fig. 2 and the distribution of our observations were determined by the ice conditions because we had to follow the boundary of the pack-ice, now and then penetrating into fairly scattered ice. In general we first followed the boundary of the ice to the northeast and then to the east, to longitude 25° E., where, on September 2, we found ourselves at the very border of the continental shelf. We could not expect to reach greater depths further to the east where the boundary of the ice as a rule bends towards the south and, therefore, we again turned west, following the ice except on a short detour towards the south on September 3. In the afternoon of that day we met the ice in the very same region as on August 25. Between September 3 and 6 we followed the ice towards the southwest, stopping occasionally for scientific observations and taking soundings by the echo method every second mile when under way. In the afternoon of September 6 we had reached the previously explored part of the Norwegian Sea, and as the ice again became densely packed under the influence of a strong northeasterly wind, it was decided to return to Spitsbergen. In the afternoon of September 7 we reached Cross Bay where the last gravity observation was taken.

On September 8 we arrived at Advent Bay after an absence from that place of exactly three weeks. Sir Hubert Wilkins planned to sail from here via Iceland to New York, if possible, and suggested that the scientists should leave the *Nautilus* and return to Norway by a ship which was sailing that very night with a load of coal. The scientific instruments were, therefore, dismounted and the equipment, except the sonic depth-finder, was brought onboard the coal steamer.

The scientists arrived in Bergen on September 17. The plan of crossing the Atlantic again with the *Nautilus* had to be given up and the *Nautilus* also proceeded to Bergen, where she arrived on September 20. Mr. Soule and Dr. Villinger both remained in Bergen a few days in order to make control observations with their instruments, and on leaving took with them the observations which they were to reduce and discuss. The other observations and collections were later on distributed to different persons and all results can be presented in the near future.

The expedition did not reach its goal and the scientific results are, therefore, small as compared to what had been hoped for. But we have shown that an extensive scientific program can be carried out under the conditions onboard a submarine, and it is hoped that the following papers will add to our knowledge of the region which was visited.

In this place I wish to emphasize that our scientific work could not have been accomplished without the unfailing interest of Sir Hubert Wilkins and the invaluable help of the officers and crew of the *Nautilus*.

The interest which Wilkins himself took in the scientific work is illustrated by the fact that on the day when the loss of the diving rudder was discovered and we actually were lying in the ice with a disabled submarine, he had no thought of returning to safety before we had tested our scientific equipment under conditions which were worse than those to be expected on a journey partly under the ice. I can, I believe, safely state that on August 22 every one onboard except Wilkins would have been willing to return, acknowledging a complete defeat, but he did not for one moment consider the possibility of returning before every opportunity for scientific work had been taken. He, therefore, deserves full credit for what has been accomplished.

The Route of the *Nautilus*

between August 19 and September 7, 1931

The route of the *Nautilus* as shown on the chart in fig. 2 is based on:

1. Bearings of known landmarks.
2. Observations of the sun for position.
3. Dead reckoning based on the readings of the patent (Stavrakof) log and the gyroscopic compass.
4. Previous soundings in the vicinity of Spitsbergen.

The accuracy of the route is of fundamental importance to the interpretation of all scientific observations and shall, therefore, be discussed in detail starting at the departure from Spitsbergen on August 19th.

On August 19 the position at 11^h was determined by bearings of the small islands off the northwestern coast of Spitsbergen and shortly afterwards the course was changed to true NE. by N. This course was held until the ice was met with and then varying courses were steered until the ice became too close to permit further advance.

The position at $17^h\ 20^m$ was originally plotted 8 miles further to the SSW. because a considerable reduction in the reading of the log was made on account of the many detours caused by the ice. When later on the soundings were compared with earlier soundings in the same region it appeared that the applied correction was too great and that a much better agreement would be obtained by neglecting the correction altogether. This led to a displacement of the position at $17^h\ 20^m$ of 8 miles in the general direction of the course between 11^h and $17^h\ 20^m$.

Between August 19, $17^h\ 20^m$ and August 21, 20^h, the vessel was drifting with the wind or now and then moving slowly under power. The sky remained overcast and no sight could be obtained. In the evening of the 21st the sky cleared in the south and northern Spitsbergen became visible. Some contours could be recognized and bearings were obtained, giving the position which is shown on the chart.

The short distance which was covered under power on August 21, between 20^h 15^m and 23^h 40^m, has been plotted according to the course by compass and distance by log and the drift with the wind from August 21, 23^h 40^m to August 22, 8^h 30^m has been estimated, taking preceding and following experiences into account.

Between August 22, 8^h 30^m and August 22, 17^h 30^m the route has been plotted according to courses by the gyroscopic compass and distances according to the log. During the following two days, when a very fresh E-wind was blowing, we moved slowly towards the WSW. partly under power and partly drifting with the wind. During the 24th the weather cleared and we obtained three observations for position, which combined, gave 81° 06.5′ N. and 8° 35′ E. Shortly after having ascertained our position we proceeded some miles towards the NE. under power but soon had to stop because we met loose ice. Between the 24th at 14^h and the 25th at 9^h we were again drifting with the wind at an estimated rate of about 0.5 knot. A single observation of the sun served as a check on our estimated position at 9^h on the 25th. From 9^h to 19^h 30^m we were under way, steering first NNE. and then N. without seeing ice before we passed 81° 50′ N. On meeting the ice the course was changed to easterly. During the 26th and the greater part of the 27th we were lying outside of the ice, drifting with the wind, which on the whole was easterly. On the 27th we obtained good observations for position, giving 81° 52′ N. and 13° 40′ E.

These and the following observations were taken with time intervals of several hours when the vessel was drifting or moving back and forth under power and the result, therefore, cannot be held accurate within more than 2 miles.

Between August 27, 19^h 15^m and August 28, 1^h 30^m, we again proceeded under power and on the 28th we obtained two observations of the sun giving 81° 59′ N., 17° 30′ E. Progress under power was resumed between August 28, 19^h 30^m, and August 29, 1^h, and on the 29th two observations of the sun gave the position 81° 51′ N. and 21° 30′ E. Our most northerly latitude according to these observations was 81° 59′ and the route has not been plotted to the north of this latitude, although it cannot be doubted that we crossed the parallel of 82° when zigzagging along the edge of the ice.

On the 30th, the 31st, and September 1st we were covering small distances under power but were mostly drifting with the wind, which on the 30th was easterly but on the 31st and the 1st, weak northerly. On September 1 observations of the sun gave the position 81° 44′ N. and 19° 15′ E.

Proceeding mainly to the east between September 1, 23^h 20^m and September 2, 6^h 40^m, we crossed the route of the *Sofia*. After the return of the expedition our soundings were found to agree exactly with those of the *Sofia*, although the crossing took place in a region where the depth increases very rapidly to the north and where a small mistake as to the latitude would give rise to great discrepancies. The agreement can be taken as evidence of correct navigation in the case of both expeditions.

On the 2nd we obtained three observations of the sun, two with sextant and one with theodolite on the ice, giving a position of 81° 38′ N. and 24° 45′ E. Between September 2, 18^h 30^m, and September 3, 17^h 55^m, we were going westward under power, except for a short interruption in the evening of the 2nd when the microphones of the sonic depth-finder were cleaned of ice. We were mostly following the ice, but on the 3rd we made a detour towards the south in order to obtain a better distribution of the soundings. The agreement between the most southerly soundings on the 3rd and the most northerly soundings on August 22, indicates that the route has been plotted correctly. This is even more strongly supported by the agreement between the last sounding on September 3 and the soundings in the same region on August 25.

On September 4 we obtained three observations of the sun, giving 81° 40′ N. and 11° 20′ E.

Practically the whole remainder of our route, between September 4, 16^h, and September 7, in the afternoon, was determined by dead reckoning and in this period very careful records were made of courses and log readings. On the 6th two observations of the sun were obtained shortly before noon and with a time-interval of one hour only. These observations gave 80° 31′ N. and 1° 10′ E. The latitude may be regarded as correct because of the small time difference from noon, but the longitude is inaccurately determined. However, the value agrees very well with the longitude according to dead reckoning and has, therefore, been adopted.

The last part of the route in the vicinity of Spitsbergen was plotted somewhat further to the south on the original map. The dead reckoning could not be expected to give very accurate results on the last stretch because a strong NNE. wind was causing a considerable drift of the ship. The route was, therefore, originally plotted by reckoning backwards from Cross Bay to the position of sounding No. 284, at which place the course had been changed to SSE. when approaching land. From the previous soundings it appears as if this procedure has led to a position of sounding No. 284 which is about 10 miles too far south. This position was, therefore, shifted 10 miles to the north and all the route changed accordingly.

When plotting the route in the vicinity of land the available soundings have thus been used, but in greater distances from the land the route is based entirely upon astronomic observations and dead reckoning. The latter of these two methods gave very good agreement in the cases in which the drift of the vessel had been small. Considering this fact and considering the obvious good agreement between the soundings along the different sectors of the route and earlier soundings in the same region it can probably be claimed that the actual position of the ship never deviated more than 2 miles from the positions shown on the map.

The observations of the depth by the sonic method have been entered along the route partly according to the record of the time at which they were taken and partly according to the log readings because later on they were taken at every second mile, following signal from the electrician on watch in the central control room. The absolute positions of soundings should thus be accurate within 2 miles, but the relative positions of the soundings are much more accurate. A displacement of the route leads to proportional displacements of all soundings. In the table showing the results of the sonic depth work the positions have been entered to the nearest 0.1′ in latitude and 1′ in longitude. This only implies that the relative positions are of an accuracy of the order of some tenths of a mile. If the positions were rounded off to the nearest mile the distances between the positions would vary irregularly and one would obtain quite a wrong picture of the actual changes in the depth.

THE ICE

The first ice was met with on August 19, in latitude 80° 20′ N. and longitude 12° E. The ice was scattered but soon became so dense that further progress of the vessel was prevented. It is very probable that this ice represented an isolated belt because water sky could be seen to the northeast and on August 20, when a strong E-wind was blowing, a swell from the east was perceptible.

During the night between the 20th and the 21st, the ice evidently was carried more to the north than was the vessel, because no ice was in sight when it cleared up in the evening of the 21st. Steering NE. the ice was again met with in 80° 46′ N. and 10° 30′ E. During the 22nd we had the ice in sight on the port side from the early morning until the afternoon, when progress towards the northeast was stopped by ice in 81° 24′ N. and 14° 20′ E. During the following days the ice again was carried much more to the north than the vessel, which was drifting before a fresh E-wind. When progress was resumed on the 25th we reached 81° 53′ N. and 11° 15′ E. before meeting the ice. Here we found the pack-ice jammed tightly together and the edge running approximately east-west.

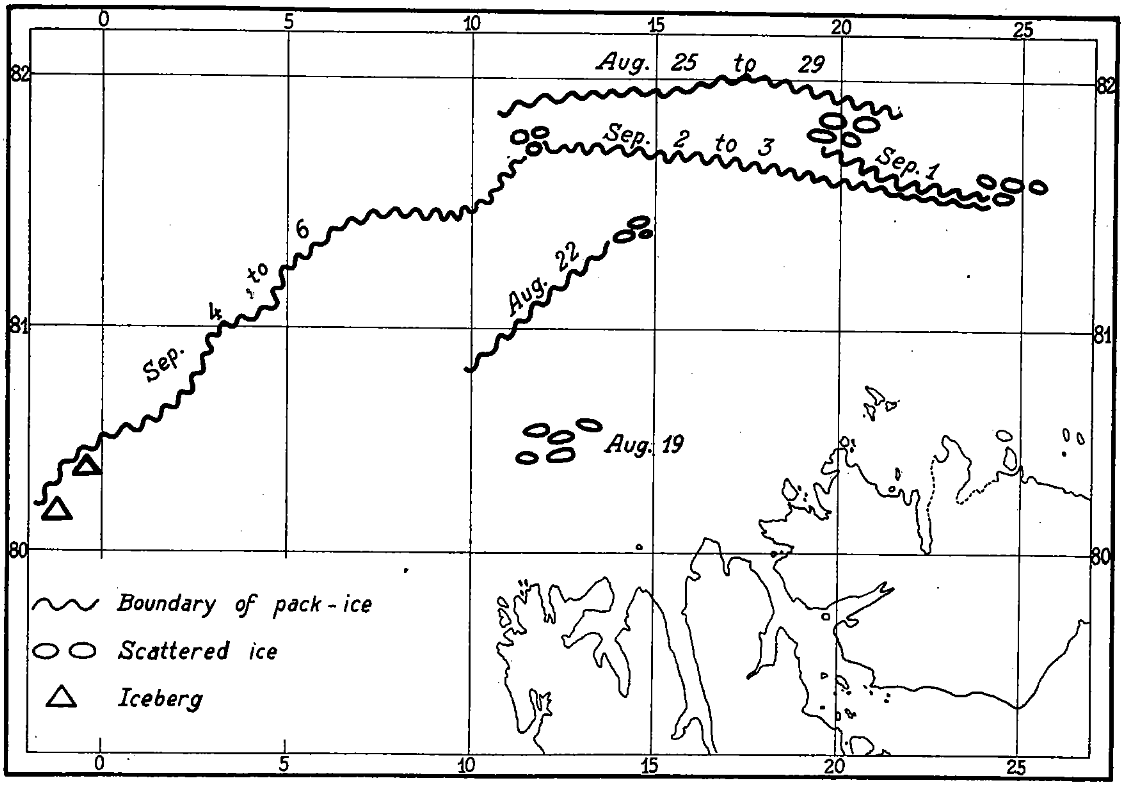

FIG. 3.—The ice to the north of Spitsbergen between August 19 and September 6, 1931

On August 25 to August 29 we followed the edge of the pack-ice in latitude about 81° 55′ N. and between longitudes 11° 15′ E. and 21° 30′ E. During these days the ice remained tightly packed under the influence of a weak east wind. The wind changed to northerly on August 30, and the ice loosened up. At the same time the edge moved towards the south and was in latitude 81° 40′ N. on the evening of September 1. During the night between September 1 and 2 we followed the ice in the general direction of E. by S. and on the 2nd we pushed about 8 miles into the pack, reaching a latitude 81° 38′ N. in longitude 24° 45′ E.

In the night between September 2 and 3, and on September 3, the border of the ice was running practically as a straight line between 81° 30′ N., 24° 30′ E. and 81° 44′ N., 11° 15′ E. At the latter position the edge bent towards the southwest.

On September 4, 5, and 6, we followed the ice in the general direction of southwest, between the last named position and 80° 10′ N., 1° 20′ W.

No iceberg had been seen in the northern latitudes but in 80° 20′ N., 0° 45′ W., and in 80° 10′ N., 1° 20′ W. we passed two icebergs. The former was quite table-formed, of an altitude of 7 to 8 meters above water and of a length of about 100 meters on either side. The latter was more irregular, reaching a greater height in some parts, and of greater extent. It is probable that these icebergs originated from some of the Spitsbergen glaciers and that before reaching their observed positions they had made only a small detour towards the north.

The accompanying chart (fig. 3) shows the boundary of the pack-ice on the different dates and the locations of the icebergs.

II. OCEANOGRAPHY

By H. U. SVERDRUP

Contribution No. 2 from the Woods Hole Oceanographic Institution

1. Introduction

One of the principal objects of the expedition was to obtain exact oceanographic observations from the deep parts of the Polar Sea, because of the importance of such data for the understanding of the currents and the properties of the waters in the Polar Sea.

From the shallow seas surrounding the Polar Sea numerous modern observations are available, *e.g.*, from Spitsbergen Waters, the Barentz Sea, the Kara Sea, the East Siberian Sea and the Chukotsk Sea, but our present knowledge of the deep Polar Sea is based entirely on the observations by Fridtjof Nansen during the drift of the *Fram* in 1893–96. At that time, however, oceanographic methods were imperfect, and Nansen's observations, therefore, lacked the accuracy which is desired in modern oceanography. Nansen himself realized this fully and he, later on, contributed more than any other person to the perfection of the methods, and special credit is due to him for the high degree of accuracy which characterizes modern oceanographic observations. In spite of the deficiencies of his observations, Nansen, in his eminent discussion, could set forth the principal features of the currents in the Polar Sea. He could show that the branch of the Gulf Stream which follows the west coast of Spitsbergen towards the north continues into the Polar Sea, where it submerges under a layer of surface water of low salinity and low temperature and can be traced as a sub-surface current across the Polar Sea to the vicinity of the New Siberian Islands.

As to the origin of the deep water and the bottom water Nansen could not reach definite conclusions because his observations of the salinity included too great errors. As to the temperature of the deep water he found an increase towards the bottom and this led him to a discussion of heating by adiabatic processes in the sea. His observations indicated a temperature-increase towards the bottom which was greater than would be expected on account of the adiabatic changes, and he attributed this to the effect of heat coming from the interior of the earth. If this is correct the deep water of the Polar Sea must be practically stagnating, but no definite conclusions can be based on observations of temperature alone.

Without entering further into details, it is evident that many questions as to the oceanographic conditions in the Polar Sea remained open and Nansen himself was strongly interested in having the deep-sea observations repeated and extended.

In 1912 he undertook a cruise to Spitsbergen with his small yacht, *Veslemoy*, hoping to reach so far north that he could obtain water-samples from great depths, but the ice conditions were not favorable. He obtained a number of valuable observations of temperature, salinity, and currents in the shallow waters but none from the deep water.

When Roald Amundsen left Norway on board the *Maud* in 1918 he hoped to repeat the drift of the *Fram*, starting from a more easterly point. The author was in charge of the scientific work, and oceanographic exploration of the deep Polar Basin had been placed foremost on the scientific program. We met unfortunate ice conditions, however, and in spite of more than six years in the Arctic we failed to reach the deep parts of the

Polar Sea. We were able to gather a great amount of scientific information but could not add any contribution to the knowledge of the deep Polar Sea.

In the meanwhile, in 1922, when the ice conditions north of Spitsbergen were favorable, Dr. Devik had succeeded in reaching beyond the continental shelf and had obtained a number of observations from depths greater than 1000 meters, down to 3000 meters. According to these observations, which are still unpublished, it is evident that the deep water of the Polar Sea is closely related to the deep water in the northern part of the Norwegian Sea, and it is probable that the former flows into the Polar Sea from the south. If this is correct it will be of great interest to follow this deep water on its further flow in the Polar Sea.

With the history of the exploration of the Polar Sea in mind, it is easily understood that the oceanographic observations on an expedition across the Polar Sea by submarine would be of very great interest. As to the selection of the route, a crossing of the Polar Sea could not be expected to give the best results from an oceanographic point of view. One single section gives a good idea of the character of the waters along this section but gives no basis for computation of currents. From the standpoint of the oceanographer it would be better to obtain several sections on the Atlantic side of the Polar Sea because here the currents have their greatest velocities and here the greatest contrasts must be present. In 1930 the author expressed this view in a letter to Sir Hubert Wilkins but added that he was fully aware that the route across the Polar Sea had advantages when considering other branches of science.

On account of many delays the plan of crossing the Polar Sea had to be abandoned because of the advanced season, and when we finally left Advent Bay, Spitsbergen, on August 18, we could at best hope to obtain a single oceanographic section between Spitsbergen and a point perhaps two hundred miles further to the north. Even this hope failed because of the loss of the diving rudder, but thanks to extraordinarily favorable ice conditions we reached in open water a higher latitude than any earlier expedition starting out from Spitsbergen by ship. Prior to 1931 the highest latitude, 81° 43′, had been reached in 1868 by A. E. Nordenskiöld onboard *Sofia*, while our most northern observation gave a latitude of 81° 59′, and it is of still greater interest to note that we were to the north of 81° 50′ between longitudes 12 E. and 20 E., in which region very few ships previously have passed the parallel of 81° and from which no oceanographic data are available. Thanks to these favorable circumstances we were able to obtain a series of observations which throw light on some of the problems relating to the currents in the Polar Sea.

As to the extent of the observations it was planned to determine temperature, salinity, oxygen content, pH-value, phosphate and nitrite nitrogen contents at standard depths, to collect organisms from different intervals of depth, to secure bottom samples, to determine the depths by the sonic method and to examine the amount and character of the light penetrating through the ice and the water to different depths. The latter examination could not be undertaken because the submarine could not go under the ice. The results of the sonic depth work and the examination of the bottom samples and the collections of organisms will be treated elsewhere and here we shall only deal with the results of the work within physical and chemical oceanography.

I have received the kind permission of Professor B. Helland-Hansen to make use of the observations of Dr. Devik onboard the *Ringsael* in 1922 and of Professor H. W:son Ahlmann to include some of the data obtained on the cruise of the *Quest* in 1931 and have used the available observations from stations at which the depth was greater than 500 meters. Our observations are of no special interest to a discussion of the conditions in the shallow parts of the sea to the north of Spitsbergen and these conditions shall, therefore, not be treated.

Here I wish to express my acknowledgment for the invaluable assistance of Sir Hubert Wilkins and Frank Crilley, master diver, when taking the observations and for the unfailing interest and helpfulness of Mr. Soule, first assistant scientist, and Dr. Villinger, physician and second assistant scientist.

INSTRUMENTS

Before entering upon a discussion of the methods of observation and the accuracy of the results a complete list shall be given of the instruments, accessories and chemicals for oceanographic work onboard the *Nautilus*.

Winches, Meter Wheels, Leads, Dynamometer: One specially built winch (Lidgerwood Mfg. Co., New York) with automatic spooling device and supplied with 6200 meters of ⅛-inch steel wire rope on the drum. The winch could be operated by hand and could be driven by means of a motor in the central control room. From this motor a shaft led forward to a clutch in the room aft of the diving compartment and the shaft upon which the drum of the winch was fastened also led to the same clutch, which could be operated from the diving compartment by means of a rod through the partition between the two chambers.

From the drum the wire passed the spooling device and a special pulley with three wheels, two upper and one lower. The two former were fastened to the upper and the latter to the lower part of two very powerful springs which were compressed when the wire was under strain. The lower wheel was provided with a series of cogwheels by means of which the length of the wire which had been paid out was registered. From the second of the two upper wheels the wire was led over a block directly above the trapdoor and, when the door was open, down into the sea.

The expedition also carried one small hand reel, containing 300 meters of ⅛-inch steel wire rope, for use from the deck, two meter wheels, two leads of 4 kg., one lead of 8 kg. and one lead of 12 kg. and one hand dynamometer for measuring the strain on the wire.

Water Bottles and Thermometers: Eighteen Nansen reversing stopcock water bottles of 1.25 liters capacity, each provided with detachable frames for two thermometers, and 18 messengers. The water bottles were provided with thermometers as follows:

BOTTLE No.	LEFT THERMOMETER	RIGHT THERMOMETER	BOTTLE No.	LEFT THERMOMETER	RIGHT THERMOMETER
1	PTR. No. 371	PTR. No. 372	10	PTR. No. 388	PTR. No. ...
2	373	374	11	389	...
3	375	376	12	390	...
4	377	379	13	391	...
5	380	381	14	392	...
6	382	383	15	393	...
7	385	...	16	394	1605
8	386	...	17	395	1607 unprotected
9	387	...	18	396	1609

The 24 thermometers with PTR-numbers between 371 and 396 were protected reversing deep-sea thermometers Model D.A.E., divided in 1/20°, interval –2° to +8°. The three thermometers with PTR-numbers 1605, 1607 and 1609 were unprotected deep-sea thermometers, Model D.A.E., divided in 1/5°, interval –2° to +60°. The expedition also carried one surface thermometer (Factory No. 83), divided in 1/10°, interval –3° to +30°, and two Nansen reading lenses for deep-sea thermometers.

Glass Bottles for Storing Water Samples: Ten boxes each containing 50 patent stopper, green glass bottles of 100 cc. for samples to be stored and examined as to chlorine content after the return of the expedition.

Equipment for Determining Density: One box with 24 patent stopper green glass bottles of capacity 300 cc. for samples to be examined onboard as to specific gravity. One Nansen hydrometer of total immersion, comprising 2 floats (Nos. 24 and 27), one set of weights (No. 14/13 B), one set thermometers (Nos. 1, 2, 3, 4, 11 and 12), graduated to 1/10°, interval –1° to +24°, Dewar vessel of 500 cc. capacity with outflow at the bottom and one glass stirrer. Constants of floaters, weights and thermometers determined at the Physikalisch-Technische Reichsanstalt in 1914.

General Equipment for Chemical Work: Four x 10 liters distilled water, two measuring bottles of 100 cc., one measuring bottle of 500 cc., two measuring glasses of 25 cc., one measuring glass of 100 cc., one measuring glass of 500 cc., two enameled containers of 3 liters, pipettes of 1, 2, 10 and 20 cc., three spare pifix pipettes and spare parts to pifix pipettes, 500 cc. cleaning solution for glass ware, 500 cc. alcohol, assorted glass bottles, glass tubes, rubber tubes, glass trays, milk glass plates, funnels, rubber tube clamps, rubber stoppers, corks, screws, files, tweezers, and nippers.

Equipment for Determining Oxygen: Three boxes each containing 24 glass bottles with ground glass stoppers and of about 100 cc. capacity. The volume of each bottle determined with an accuracy of 0.1 cc. Rubber hose with glass tube for filling bottles. Two pifix pipettes of 1 cc. for $MnCl_2$- and NaOH-solutions, two special bottles by Sund (see fig. 4), three x 500 cc. $MnCl_2$-solution (200 gr. $MnCl_2 + 4H_2O$ in 500 cc. distilled water), three x 500 cc. NaOH-solution (180 gr. NaOH + 50 gr. KI in 500 cc. distilled water), one pifix pipette of 2 cc. for HCl, three x 500 cc. HCl (3 parts concentrated HCl to 1 part distilled water), two titration apparatuses by Krawczynski with burettes of 25 cc. capacity, divided to 1/10 and one brown double-necked Woulff bottle of 2 liters, one extra Woulff bottle, one reading lens for burettes, two automatic 10 cc. pipettes, 6 Erlenmeyer flasks, two wash bottles, three x 500 cc. starch solution, 2 x 4 gr. starch, about 100 gr. KI, two x 1000 cc. 1/10 normal $Na_2S_2O_3$-solution, three x 500 cc. standard KIO_3HIO_3-solution (0.6499 gr. to 1000 cc. distilled water).

Equipment for Determining pH: Two boxes each containing 24 wide-necked glass bottles (Pulverhafen) with ground glass stoppers, one pifix pipette of 2 cc. in special bottle, one Sund mixing glass of 100 cc. (fig. 4), three x 1000 cc. phenolphthalein-solution (1 permille in 70 per cent alcohol), one x 1000 cc. α-naphtholphthalein-solution (1 permille in 70 per cent alcohol), one colorimeter by Sund [1931], to be used for determination of phosphates as well and supplied with two wedges, containing red solutions of weak and strong color, obtained by mixing solutions of safranin and borax-methylen blue and sterilized by a drop of sublimate, two wedges for distilled water, three glass and two brass tubes with funnel-shaped openings, one glass of saphranin and one glass of borax-methylen blue. Two x 100 cc. red solution for refilling wedges of colorimeter, two sets pH-standards from Laboratoire Hydrographique, Copenhagen.

Equipment for Determining Phosphates: Two boxes each containing 24 wide-necked glass bottles (Pulverhafen) with ground glass stoppers, one pifix pipette of 1 cc. in special filling bottle for Ammonium-molybdate, two x 1000 cc. Ammonium-molybdate (2.5 per cent solution in 38 per cent sulphuric acid), one x 250 cc. sulphuric acid, about 10 gr. $SnCl_2$, two drop glasses, one x 500 cc. KH_3PO_4-solution (10,000 mg. P_2O_5 per liter), one x 500 cc. KH_3PO_4-solution (1,000,000 mg. P_2O_5 per liter), one tube $Na_2HPO_4 + 12\ H_2O$, two graduated pipettes of 1 cc. Colorimeter as mentioned above under pH, containing two wedges filled with borax-methylen blue solutions, one of strong and one of weak color.

Equipment for Determining Nitrite Nitrogen: One box containing 24 wide-necked glass bottles (Pulverhafen) with ground glass stoppers, two x 500 cc. sulphanilic acid in acetic acid (1.7 gr. sulphanic acid in 25 gr. acetic acid and 475 cc. distilled water), ten x 100 cc. α-naphthylamine in acetic acid (0.6 gr. α-naphthylamine in 44 gr. acetic acid and 956 cc. distilled water), three x 1 gr. $NaNO_2$, two x 100 cc. $NaNO_2$-solution (100,000 mg. N per m^3), two graduated pipettes of 5 cc., one graduated pipette of 1 cc.

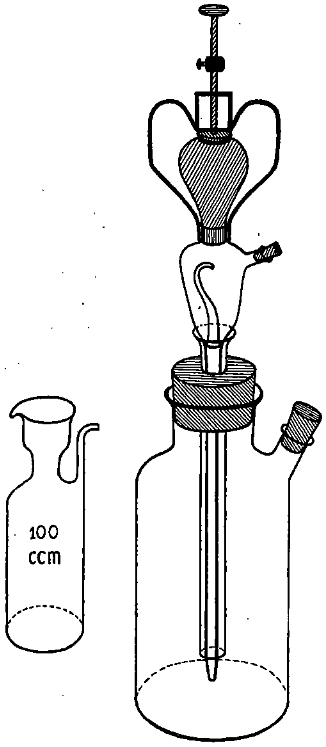

Fig. 4.—Special glass bottle for pifix pipettes and special mixing bottle by Sund.

Bottom Samplers: Two bottom samplers designed for bringing up cores, of the pattern used on the *Meteor*-expedition but made in Bergen under the supervision of the writer. The principal part of the bottom sampler consists of an iron tube which contains a steel tube, lined with a glass tube. The inner steel tube is held in position by an end-piece which has an opening 2 cm. in diameter, equal to the inner diameter of the glass tube. The latter is 1 m. long. Three detachable leads are placed at the upper end of the iron tube, the total weight with leads is 38 kg. The iron tube is open at the top when being lowered but the opening is closed by a valve when hauling up. A snapper is released when the sampler strikes the bottom and this snapper falls down and closes the lower end of the tube as soon as it emerges from the mud. Twenty glass tubes for the bottom samplers had been procured and a special box made for these.

Equipment for Biological Work: One continuous plankton recorder by Dr. A. C. Hardy, complete with accessories. This instrument unfortunately got out of order and no records were obtained. Four Nansen closing nets, diameter of opening 40 cm., length 4 m., of standard Swiss bolting silk No. 25, six Nansen closing nets, diameter of opening 60 cm., length 4 m., of standard Swiss bolting silk No. 10, three Nansen closing mechanisms with messengers, spare parts, bottles for preserving samples, formalin and alcohol for preserving samples.

Spectrograph and Light Sensitive Cells: One small quartz spectrograph with internal wave length scale (Adam Hilger, Ltd., London, No. E 37). Accessories and Barnet plates.

The spectrograph was not used. Potassium-cell with sensitive galvanometer and Copper-oxydul-cell, both obtained through the kind assistance of Professor F. Linke, Frankfurt a.M. The cells were not used.

WORK AT STATIONS

STATION No. 0. (Bottom sample only.) August 26, 1931, 81° 54′ N., 14° 10′ E. Depth by sonic depth-finder 1606 m. In the diving compartment: Danenhower, Crilley, Sverdrup, Wilkins. Door closed at $12^h\ 40^m$. Bottom sampler attached to stray line, 50 m. long, lowering begun at $13^h\ 30^m$. Much trouble with wire because the spooling device had failed to function when wire was originally laid on drum. On that occasion the strain on the wire had been very uneven and parts of the wire were, therefore, pressed deep down between other parts. Bottom struck at $15^h\ 30^m$, length of wire and stray line 1680 m., wire angle greater than 20°. Hauling in at $15^h\ 40^m$. Bottom sampler up at $16^h\ 30^m$, bringing core 42 cm. in length. Plankton recorder down at $16^h\ 50^m$. Vessel pitching, water occasionally splashing into the compartment. Door opened at $17^h\ 15^m$.

STATION No. 1. August 27, 1931, 81° 52′ N., 13° 30′ E. Depth by sonic depth-finder at beginning 1606 m. and at end 1606 m. In the diving compartment: Crilley, Sverdrup, Villinger, Wilkins. Door closed at 8^h. Plankton recorder up at $8^h\ 10^m$.

Series I. Decided to try to obtain bottom sample and water samples from the greatest depths in one haul. Bottom sampler attached to stray line of rope, 50 m. long, lowering begun at $8^h\ 20^m$. Water bottles Nos. 16, 1 and 2 attached at distances 100, 400 and 600 respectively from the bottom sampler. Bottom struck at $8^h\ 45^m$, length of wire and rope stray line 1670 m., wire angle greater than 20°. The wire angle had to be roughly estimated because at angles greater than about 10° the wire was pressed against the walls of the well in the diving compartment. Messenger down at $8^h\ 46^m$, reeling in at $9^h\ 13^m$, bottom sampler up at $9^h\ 50^m$, bringing core 44 cm. in length. All water bottles and thermometers functioned properly.

Series II. Lowering begun at $10^h\ 05^m$. Water bottles Nos. 3, 7, 8, 4 and 10 attached to wire at distances 20, 220, 420, 520 and 620 m. from the end of the wire, total length paid out: 720 m. at $10^h\ 20^m$, wire angle greater than 20°. Messenger down at $10^h\ 24^m$, reeling in at $10^h\ 32^m$, last water bottle up at $10^h\ 45^m$. At $10^h\ 50^m$ started clearing the wire by paying out. Vessel drifting so much that wire did not get entangled but was stretched out on the bottom. Wilkins lying under the winch and clearing the wire as it ran out. Total length, 6200 m., paid out at $13^h\ 48^m$, reeling in at $14^h\ 25^m$, all in at $15^h\ 55^m$. Plankton recorder down at $16^h\ 05^m$. Door opened at $16^h\ 15^m$.

All thermometers read and samples for determination of salinity, oxygen, pH, phosphates and nitrites taken by Soule and Sverdrup between 17^h and 18^h. Chemicals added to oxygen samples immediately. Large samples for determining density from water bottles Nos. 7, 2, 1 and 16.

pH, phosphates and nitrites determined by Sverdrup and Villinger between 20^h and $22^h\ 30^m$.

STATION No. 2. August 28, 1931, 81° 59′ N., 17° 30′ E. Depth by sonic depth-finder 2615 m. In the diving compartment: Crilley, Soule, Sverdrup, Wilkins. Door closed at $8^h\ 15^m$. Plankton samples up at $8^h\ 25^m$.

Series I. Bottom sampler attached to stray line of rope, 20 m. long, lowering begun at $8^h\ 30^m$. Water bottles Nos. 16, 1, 2, 3 and 17 attached to wire at distances 40, 560, 1060, 1360 and 1560 m. from the bottom sampler. Bottom struck at $9^h\ 20^m$, length of wire and stray line 2780 m., wire angle greater than 20°. Messenger down at $9^h\ 22^m$, reeling in at $9^h\ 48^m$, bottom sampler up at $11^h\ 50^m$, bringing core 35 cm. in length. Right-hand thermometer of bottle No. 1 had failed to record. Samples for determination of salinity, oxygen, pH, phosphates and nitrites taken and thermometers of water bottle No. 17 read at once, oxygen sample destroyed because pifix pipettes failed to function under pressure.

Series II. Lowering begun at $11^h\ 05^m$. Water bottles Nos. 17, 7, 8, 4, 9, 10, 11 and 12 attached to wire at distance 20, 220, 320, 420, 520, 620, 720 and 770 m. from end of wire, total length paid out, 817 m. at $11^h\ 20^m$, wire angle greater than 20°. Messenger down at $11^h\ 25^m$, reeling in at $11^h\ 30^m$, last bottle up at $11^h\ 44^m$. Thermometers on water bottles Nos. 10 and 11 failed to function.

Plankton samplers down at $12^h\ 00^m$. Door opened at $12^h\ 10^m$.

Thermometers read and samples for determination of salinity, oxygen, pH, phosphates and nitrites taken by Soule, Sverdrup and Villinger between $12^h\ 30^m$ and $13^h 15^m$. Large samples for determining density taken from water bottles Nos. 17, 1 and 16.

pH, phosphates and nitrites determined by Sverdrup and Villinger between $17^h\ 30^m$ and $20^h\ 30^m$, oxygen at stations Nos. 1 and 2 determined by Soule between 18^h and 20^h.

STATION No. 3, August 29, 1931, 81° 50′ N., 21° 30′ E. No depth by sonic depth-finder because echo too weak. In the diving compartment: Crilley, Soule, Sverdrup, Wilkins. Door closed at $9^h\ 00^m$. Plankton samples up at $9^h\ 10^m$.

Series I. Bottom sampler attached to stray line, 20 m. long, lowering begun at $9^h\ 16^m$. Water bottles Nos. 16, 4, 2 and 3 attached to wires at distances 40, 540, 1040 and 1540 m. respectively from the bottom sampler. Bottom struck at $9^h\ 45^m$ but some wire paid out after striking the bottom. Difficult to observe because of pitching. Total length of wire and stray line after stop: 3660 m., wire angle between 10 and 20 degrees. Messenger down at $9^h\ 46^m$, reeling in at $10^h\ 07^m$, bottom sampler up at $11^h\ 00^m$. The upper water bottles properly reversed, but lower 60 m. of wire entangled and lowest water bottle not reversed. Bottom sampler functioned properly, bringing up core 36 cm. in length. Samples for determination of oxygen taken at once but chemicals added when pressure had been reduced.

Work discontinued because swell increasing, ship pitching and water splashing into the diving compartment. Door opened at $11^h\ 15^m$.

Thermometers read and samples for determining salinity, oxygen, pH, phosphates taken by Soule and Sverdrup between $12^h\ 30^m$ and 13^h.

pH and phosphates determined by Sverdrup and Villinger between $14^h\ 30^m$ and $15^h\ 15^m$, oxygen determined by Soule between $14^h\ 30^m$ and $15^h\ 30^m$, density of 6 samples from stations Nos. 1 and 2 determined by Sverdrup between 18^h and $19^h\ 20^m$.

STATION No. 4. August 30, 1931, 81° 50′ N., 20° 15′ E. Observations from the surface layers, taken from the deck by Sverdrup and Wilkins between 15^h and $15^h\ 20^m$. Water bottles Nos. 2, 3, 4, 7 and 8 at distances 5, 30, 55, 80 and 95 from the end of the wire, total length paid out: 105 m., reckoned from the surface of the water.

Plankton collected by closing nets between $15^h\ 25^m$ and $15^h\ 55^m$ from depth intervals 50 to 0 m. (silk No. 25), 100 to 50 m. (silk No. 25) and 250 to 100 m. (silk No. 10).

Thermometers read by Sverdrup and samples for determining salinity, oxygen, pH, phosphates and nitrites taken by Soule and Sverdrup between 16^h and 16^h 30^m.

pH, phosphates and nitrites determined by Sverdrup and Villinger between 17^h and 17^h 45^m.

STATION No. 5. September 2, 1931. 81° 38′ N., 24° 45′ E. Depth by sonic depth-finder 668 m. at beginning and 429 m. at end. In the diving compartment: Crilley, Soule, Sverdrup and Wilkins. Door closed at 7^h 45^m. Bottom sample only. Bottom sampler attached to stray line 20 m. long, lowered at 7^h 55^m, struck at 8^h 00^m total length of wire and stray line 560 m., reeling in at 8^h 04^m, bottom sampler up at 8^h 15^m. No sample in glass tube, apparently because mud so soft that it slid out of tube when hauling up. Bottom sampler provided with new glass tube attached to end of wire when taking Series I.

Series I. Bottom sampler attached to end of stray line 20 m. long, lowering begun at 8^h 25^m. Water bottles Nos. 16, 2, 7 and 3 attached to wire at distances 40, 160, 260 and 360 m. respectively from bottom sampler. Bottom struck at 8^h 40^m, total length of wire and stray line 560 m., no wire angle. Messenger down at 8^h 44^m, reeling in at 8^h 50^m, bottom sampler up at 9^h 04^m. No sample in tube although the whole length of the sampler had penetrated down in the mud. Samples for determining oxygen taken at once, but chemicals added when pressure had been reduced.

Series II. Lowering begun at 9^h 08^m, water bottles Nos. 17, 4, 8, 12, 1 and 9 attached to wire at distances 20, 70, 95, 120, 145 and 160 m. respectively from the end of the wire. Total length paid out at 9^h 18^m, 167 m., no wire angle. Messenger down at 9^h 24^m, reeling in at 9^h 26^m, last bottle up at 9^h 35^m. Thermometer of water bottle No. 12 failed to record.

At 9^h 47^m plankton net lowered, paying out to 110 m., wire angle 30°. Hauling in at 9^h 47^m, net closed at 9^h 55^m when 55 m. out, up at 10^h 00^m. Lowered again, paying out 50 m., wire angle about 30°. Hauling in from 50 m. to top of water in well, 3 m. below surface of water, between 10^h 23^m and 10^h 30^m. Plankton recorder lowered at 10^h 50^m. Door opened at 11^h 15^m.

Thermometers read and samples for determining salinity, oxygen, pH, phosphates and nitrites taken by Soule and Sverdrup between 11^h 30^m and 12^h 15^m, except samples for oxygen from series I, which were taken when under pressure.

pH, phosphates and nitrites determined by Sverdrup and Villinger between 17^h and 20^h, oxygen at stations Nos. 4 and 5 determined by Soule on September 3 between 12^h and 13^h 30^m.

STATION No. 6. September 4, 81° 40′ N., 11° 20′ E. Depth by sonic depth-finder 1599 m. In the diving compartment: Crilley, Soule, Sverdrup, Wilkins. Door closed at 12^h 15^m. Plankton recorder up at 12^h 30^m.

Series I. Bottom sampler attached to stray line of rope, 20 m. long, lowering begun at 12^h 40^m. Water bottles Nos. 16, 2, 7, 3 and 8 attached to wire at distances 40, 410, 610, 810 and 1010 m. respectively from bottom sampler. Bottom struck at 12^h 53^m, length of wire and stray line 1690 m., no wire angle. Messenger down at 12^h 58^m, reeling in at 13^h 09^m, bottom sampler up at 13^h 35^m, bringing a core 38 cm. in length. Samples for determining oxygen taken at once, chemicals added when pressure had been reduced.

Series II. Lowering begun at 13^h 38^m, water bottles Nos. 17, 9, 1, 10, 4, 11 and 12 attached to wire at distances 20, 120, 220, 320, 420, 470 and 495 respectively from the end of the wire. Total length paid out at 13^h 47^m, 517 m., no wire angle. Messenger down at 13^h 52^m, reeling in at 13^h 57^m, last water bottle up at 14^h 05^m.

Plankton net lowered, paying out 115 m., wire angle about 30°. Hauling in at 14^h 20^m, net closed at 14^h 27^m when 55 m. out, up at 14^h 32^m. Lowered again, paying out 50 m., small wire angle, hauling in from 50 m. to top of water in well between 14^h 40^m and 14^h 46^m. Door opened at 15^h.

Thermometers read and samples for determining salinity, oxygen, pH, and phosphates taken by Soule and Sverdrup between 15^h 30^m and 16^h 15^m, except samples for oxygen from series I which were taken when under pressure.

pH and phosphates determined by Sverdrup and Villinger and oxygen by Soule between 19^h 15^m and 20^h 15^m.

STATION No. 7. September 5, 1931, 81° 24′ N., 6° 50′ E. Depth by sonic depth-finder 787 m. In the diving compartment, Crilley, Sverdrup, Wilkins. Door closed at 4^h 40^m.

Series I. Bottom sampler attached to stray line of rope, 20 m. long, lowering begun at 4^h 52^m. Water bottles Nos. 16, 1, 7, 2 and 8 attached to wire at distances 40, 190, 390, 590 and 690 m. respectively from bottom sampler. Bottom struck at 5^h 08^m, length of wire and stray line 810 m., wire angle greater than 20°. Messenger down at 5^h 12^m, reeling in at 5^h 18^m, bottom sampler up at 5^h 33^m, bringing core 37 cm. in length. Left thermometer on bottle No. 16 failed to record.

Series II. Lowering begun at 5^h 41^m, water bottles Nos. 3, 11, 4 and 12 attached to wire at distances 20, 700, 725 and 750 m. from end of wire, total length, 773 m., paid out at 5^h 52^m, wire angle about 10°. Messenger down at 5^h 58^m, reeling in at 6^h 03^m, last water bottle up at 6^h 15^m. Plankton net lowered, paying out 50 m., large wire angle. Hauling in between 6^h 25^m and 7^h 03^m. Net came up closed, depth of closing unknown. Door opened at 7^h 15^m.

Thermometers read and samples for determining salinity, oxygen, pH, phosphates and nitrites taken by Soule and Sverdrup between 7^h 15^m and 8^h 00^m.

pH determined by Sverdrup and Villinger between 9^h 45^m and 10^h 15^m.

STATION No. 8. September 5, 1931, 81° 01′ N., 4° 15′ E. Depth by sonic depth-finder 704 m. at beginning and 750 m. at end. In the diving compartment: Crilley, Sverdrup, Wilkins. Door closed at 13^h 15^m.

Series I. Bottom sampler attached to stray line of rope, 20 m. long, lowering begun at 13^h 30^m, water bottles Nos. 17, 1, 2, 7 and 3 attached to wire at distances 40, 200, 300, 400 and 500 from bottom sampler. Bottom sampler struck at 13^h 42^m, total length of wire and stray line 750 m., wire angle about 5°. Messenger down at 13^h 47^m, reeling in at 13^h 53^m, bottom sampler up at 14^h 00^m, bringing core 34 cm. in length.

Series II. Lowering begun at 14^h 05^m, water bottles Nos. 8, 4, 10, 11 and 12 attached to wire at distances 20, 120, 145, 170 and 195 m. from the end, total length of 217 m. paid out at 14^h 10^m, no wire angle. Messenger down at 14^h 15^m, reeling in at 14^h 17^m, last bottle up at 14^h 22^m.

Plankton net lowered, paying out 50 m., wire angle great. Hauling in between 14^h 40^m and 14^h 48^m. Door opened at 15^h 10^m.

Thermometers read and water samples for determining salinity, oxygen, pH, phosphates and nitrites taken by Soule and Sverdrup between 15^h 30^m and 16^h 15^m.

pH from station No. 8 and phosphates and nitrites from stations Nos. 7 and 8 determined by Sverdrup and Villinger between 19^h and $20^h\ 45^m$, oxygen from stations Nos. 7 and 8 by Soule between 19^h and $20^h\ 30^m$.

STATION No. 9. September 6, 1931. 80° 31′ N., 1° 10′ E. Depth by sonic depth-finder 3133 m. In diving compartment: Crilley, Sverdrup, Wilkins. Door closed at $7^h\ 50^m$.

Series I. Bottom sampler attached to stray line of rope, 20 m. long, lowering begun at $8^h\ 10^m$. Water bottles Nos. 17, 2 and 3 attached to wire at distances 50, 550, and 1050 m. from the bottom sampler. Wire angle great, ship pitching. Bottom sampler probably struck when 3400 m. paid out but because of uncertainty a total length of 3835 was paid out before stopping at $9^h\ 35^m$. Backed with motors before releasing messenger. Messenger down at $9^h\ 46^m$, reeling in at $9^h\ 58^m$. First water bottle, No. 3, had reversed properly, but second water bottle, No. 2, came up in loop of wire and was not reversed. When 450 m. wire left bad loop, wire badly kinked; when 250 m. left new loop which loosened at touch and wire with bottom sampler and water bottle No. 17 dropped down with a jerk, probably reversing the latter. Bottom sampler finally up at $11^h\ 15^m$, bringing core 42 cm. in length. Work discontinued because of increasing swell. Door opened at $11^h\ 15^m$.

Thermometers read and water samples for determining salinity, oxygen, pH and phosphates taken by Soule and Sverdrup between 12^h and $12^h\ 30^m$.

pH and phosphates determined by Sverdrup and Villinger between 17^h and 18^h, oxygen measured by Soule on September 7 while hove to in Cross Bay.

METHODS AND ACCURACY OF RESULTS

TEMPERATURE

CORRECTIONS TO BE APPLIED TO THE READINGS OF THE THERMOMETERS. The thermometers were all tested at the Physikalisch-Technische-Reichsanstalt, Charlottenburg. The corrections of the protected thermometers were rounded to the nearest 1/100° and the corrections of the unprotected thermometers to the nearest 1/50°. In order to facilitate the application of the PTR corrections and the corrections of the readings to temperatures *in situ* graphical tables were prepared for each thermometer.

A correction [Schumacher 1923]:

$$\Delta T = [(T' + v_o)(T' - t)/6100]\,[1 + [(T' + v_o) + (T' - t)]/6100]$$

as is well known has to be applied to the reading of a protected thermometer when it is read at a temperature which differs from the temperature at which the column of mercury broke off. T' is the reading of the reversing thermometer, t the corrected reading of the auxiliary thermometer, v_o the volume of mercury of the reversing thermometer at 0°, expressed in degrees, and 6100 is a constant depending upon the quality of the glass. Even values of ΔT were selected and values of t corresponding to these even values and to even values of T' were computed. On the basis of these computations, lines showing equal values of ΔT were constructed in a T', t diagram and finally these lines were displaced according to the PTR corrections at given values of T'. The corrections of the auxiliary thermometers were so small that they could be disregarded. From the resulting diagram the combined value of the scale correction and the reduction correction is easily found by means of the two readings of the thermometers. A specimen of these diagrams is shown in fig. 5. The thermometers were read with an accuracy of 1/200°, and the combined correction with an accuracy of 1/1000°, but the corrected temperatures were finally rounded off the nearest 1/100° because the PTR-correction was not given with any greater accuracy.

In case of the unprotected thermometers a somewhat different procedure had to be followed. The reduction-correction of the unprotected thermometers is, with sufficient accuracy [Schumacher 1923]:

$$\Delta T = (T' + v_o)(T_w - t)/6100$$

where T' is the reading of the pressure thermometer, T_w the temperature *in situ* as obtained by means of the protected thermometer, t the corrected reading of the auxiliary thermometer of the unprotected thermometer and v_o the volume of mercury at 0° of the unprotected thermometer. A graph representing the correction in a T', $(T_w - t)$ diagram was prepared and the lines were displaced according to the scale corrections of the unprotected thermometer. By means of the reading T' and the difference $(T_w - t)$ the corrections could be read off conveniently from these diagrams. A specimen is shown in fig. 6.

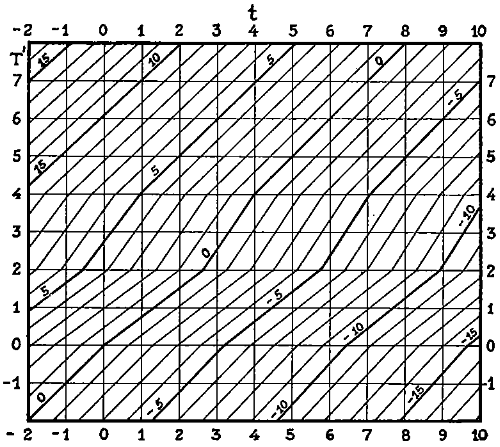

Fig. 5.—Specimen diagram from which the total correction of protected thermometer PTR. No. 371 can be read off in 1/100° by means of the reading of the main thermometer, T', and the auxiliary thermometer, t. PTR. correction of April 28, 1931, used.

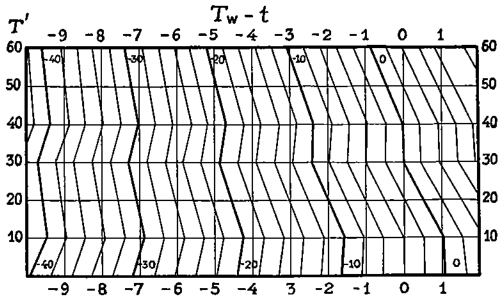

Fig. 6.—Specimen diagram from which the total correction of unprotected thermometer PTR. No. 1605 can be read off in 1/100° by means of the reading, T', of the main thermometer and the difference $T_w - t$. PTR. corrections of February 14, 1930, used.

Agreement between the Readings of Two Observers. In 88 cases the protected thermometers were read by two observers, Soule and Sverdrup. The differences between the corrected readings were examined before rounding them off to the nearest 1/100° and were found to be smaller than 0.003° in 61 per cent of the cases as is evident from the following compilation:

Interval of differences in 1/1000°	−11 to −4	−3 to 3	3 to 11
Number of cases	17	54	17
Percentage	19	61	19

It is seen that the differences have an accidental character because the number of negative differences equals the number of positive differences. The mean difference with regard to sign is –0.00025° and without regard to sign 0.003°. The result is in agreement with Böhneke's [1927] statement that the errors of reading are about ± 0.003°.

In nine cases the unprotected thermometers were read by the two observers and the differences were as follows:

Difference in 1/100°	–2	–1	0	1	2
Number of cases	1	1	5	1	1

the mean difference with regard to sign being 0, and without regard to sign 0.007°.

Agreement between Different Thermometers. Of the thermometers in use during the expedition 8 were used in pairs. Within the pair 371–372, No. 372 failed to function at station 2, but from station 5 on, it again functioned properly. At station 1 the two thermometers were in perfect agreement but at stations 5 to 8 thermometer No. 372 gave a temperature which, taking the average readings of both observers, was 0.015° higher than the temperature by thermometer No. 371. Therefore it has been assumed that the scale correction of No. 372 had changed and this correction has, therefore, been decreased by 0.01°. The other thermometers agreed so well that no change in the scale corrections was undertaken on the basis of the comparison. After changing the scale correction of No. 372 we found the following difference between the thermometers which were used in pairs:

Thermometer pairs	No. 371–372	No. 373–374	No. 375–376	No. 377–379
Difference by Soule	–0.005	–0.004	–0.005	–0.006
Difference by Sverdrup	–0.002	–0.002	–0.005	–0.006

The differences are all within the limits of the accuracy with which the scale corrections have been determined and the agreement between the different thermometers, therefore, is very satisfactory. It is noteworthy, however, that all the differences have the same sign. The first thermometer was in all cases used as the left hand and the last thermometer as the right hand one, and the left hand thermometer was always read first. The readings were taken at low temperature and it is quite possible that the systematic character of the difference is due to the heating of the right hand thermometer by the body of the observer and to the circumstance that the main thermometer reacts more rapidly to such heating than does the auxiliary thermometer. That such a heating took place is evident from the fact that the right hand auxiliary thermometer as a rule showed a higher temperature than the left hand which was read off first, the mean difference being 0.05°. Our result shows that it is necessary to place the thermometers in a water bath if the highest possible degree of accuracy is to be obtained. The discrepancy between the results of the readings of the right and left thermometer is, however, so small that the mean value of the two thermometers is not influenced by more than a few thousandths of a degree, and the mean value must be considered correct within less than one one-hundredth of a degree.

In the tables of results all temperatures are entered to the nearest 1/100° and according to the above the last decimal place may be regarded as correct.

DEPTHS

The depths at which the water bottles were reversed were determined, as a rule, by means of the wire length. But in order to obtain a check on the readings of the meter wheel and to obtain some means of correcting for wire angle, in case the wire was not vertical, an unprotected thermometer was used together with a protected thermometer at the lowest water bottle of each series.

The depths have been computed from the corrected readings of the two thermometers by means of the formula:

$$D = \frac{Tu - T}{q} \cdot \frac{1}{\rho_m}$$

where T_u means the corrected reading of the unprotected thermometer, T, the water temperature *in situ*, q is a constant which has been determined at the Physikalisch Technische Reichsanstalt and ρ_m is the mean density from the surface to the depth in question.

Table 1 contains the data which were obtained with the two unprotected thermometers which were used, the readings of the meter wheel and the approximate wire angles. These are only estimated because at wire angles greater than about 10 degrees the wire pressed against the lower part of the well in the diving chamber and the angle could not be measured.

TABLE 1.—*Depths by Wire and by Thermometers*

STAT. No.	T_u °C.	T °C.	$T_u - T$ °C.	ρ_m	DEPTH BY THERM. m.	LENGTH OF WIRE m.	DIFF. m.	WIRE ANGLE °
Thermometer No. 1605, q = 0.09836								
1	14.61	−0.91	15.52	1.032	1529	1570	41	>20
2	25.76	−0.85	26.61	1.034	2616	2740	124	>20
5	7.08	1.80	5.28	1.029	522	520	−2	<10
6	15.72	−1.01	16.73	1.032	1648	1650	2	0
7	6.97	−0.15	7.12	1.029	704	770	66	>20
Thermometer No. 1607, q = 0.09352								
2	10.54	−0.47	11.01	1.031	1142	1220	78	>20
2	8.31	0.75	7.56	1.030	785	800	15	>20
5	4.89	3.43	1.46	1.028	152	150	−2	<10
6	6.64	1.83	4.81	1.029	500	500	0	0
8	6.64	−0.07	7.71	1.029	697	710	13	5
9	4.14	1.59	2.55	1.028	265			

The table also shows the corresponding wire lengths and the differences between the thermometer depths and the wire lengths. It is seen that at small wire angles we obtained a good agreement between the depths by thermometer and the length of the wire. In 5 cases the wire angle was smaller than 10 degrees and the mean values are: Depth by thermometers 704 m., length of wire 706 m., difference 2 m. In 5 cases the wire angle was greater than 20 degrees and the mean values are: Depth by thermometers 1355 m., length of wire 1420 m., difference 65 m.

These observations give a good check on the readings of the meter wheel and make it possible to compute the actual depths at which the water bottles were reversed when the wire angle was great, assuming that the wire formed a smooth curve of the same character as, for instance, the curve which was found by the observations onboard the *Carnegie*. All the original readings of the meter wheel have been corrected according to the observations by unprotected thermometers, and the resulting depths may be considered correct within a few meters.

SALINITY

Water samples were stored in order to be examined as to chlorine content, after the return of the expedition. All were titrated in the ordinary way at the Geophysical Institute in Bergen in the last week of September, about three weeks after they had been collected. From the values of the chlorine content the salinity was computed by means of Knudsen's tables.

All samples were titrated twice and two samples were titrated three times because the difference between the results of the two first titrations exceeded 0.02 °/oo in salinity. The means of the two titrations are entered in the Table of Results under the headline "Salinity"; and since the results of two titrations as a rule deviated less than 0.02 °/oo, the average difference being 0.008, one may assume that the values in the table are correct within ± 0.01 °/oo. The regular variation with depth, to which we shall return later on, indicates that an accuracy of ± 0.005 °/oo was reached, as is possible by means of burettes of the latest construction.

DENSITY

The density of a few samples was examined onboard by means of Nansen's hydrometer. From the observed values of the density at a temperature t the corresponding values of σ_o were found by means of Knudsen's tables.

By means of Nansen's hydrometer it is possible, when working under favorable conditions, to obtain an accuracy of a few units in the 6th decimal place of the density or the third decimal place of σ_o. In our case the accuracy may be less, especially because some of the water samples were small.

The constants of the instrument, viz., the weights, volumes and temperature-coefficients of the floats, the corrections of the weights and the thermometers, had not been examined since 1914 and errors might arise from changes, especially of the thermometers. The same instruments had, however, been used extensively onboard the *Maud*, 1918–25, and several determinations of the density of distilled water had then given perfect agreement with the tabulated values at the temperature of observation. In order to obtain a corresponding check on the accuracy of the instrument two determinations of the density of distilled water at temperatures of 8.98° and 8.75° were made at the Geophysical Institute in Bergen on March 3, 1932, using float No. 24, which was used on the expedition. The results were:

t	ρ OBSERVED	ρ FROM KNUDSEN'S TABLE [KRÜMMEL 1907]	DIFFERENCE
8.98	9.999 814	9.999 809	0.000 005
8.75	9.999 830	9.999 824	0.000 006

The errors of the observations thus amount to only 5 and 6 units in the sixth decimal place of the density or about 5 units in the third decimal place of σ. An accidental error of this magnitude may be expected and there is no reason to assume that the constants of the instrument have changed to any appreciable degree. The error of one single determination of density by means of our hydrometer of total immersion ought to be smaller than ±0.01 in σ_θ.

OXYGEN

The oxygen content of the water samples was determined by means of the Winkler method. The collection and first treatment of the water samples have already been described and the titrations, which were made by Mr. Soule, need no further comments except that the standard solution which was used for determining the normality of the $Na_2S_2O_3$-solution kindly had been examined by Dr. Gaarder at the Biochemical Laboratory of the Bergens Museum and found to be exactly correct.

When dealing with the work at the stations it was mentioned that at station No. 3 samples for determining the oxygen content were taken from the water bottles directly after they came up, when the air pressure in the diving compartment still was between 1/3 and 1/2 atmosphere above normal, and also a few hours later when the pressure had been reduced to normal. The former samples all gave higher values of oxygen content than the latter, as is evident from the following compilation:

STATION NO. 3	OXYGEN CONTENT IN ml/L OF SAMPLE TAKEN		
DEPTH, M.	UNDER PRESSURE	AT ATMOSPHERIC PRESSURE	DIFFERENCE
2000	6.88	6.70	0.18
2500	6.95	6.71	0.24
3000	6.97	6.73	0.24

This difference was very puzzling. We were inclined to believe that a decrease of the oxygen content took place when the water bottles were hanging full of water for several hours, although this explanation appeared very doubtful. In order to avoid possible errors of this kind we took samples for oxygen from the water bottles of the first series as soon as the bottles came up at stations 5 and 6, but at stations 7, 8 and 9 all samples were taken when the pressure had been reduced, because at these stations the work could be finished so rapidly that no long time would elapse before the water bottles could be completely emptied.

After the return of the expedition the writer returned on several occasions to the question as to the cause of the different values of the oxygen content at station 3 without arriving at any satisfactory explanation. During a visit to Berlin in February, 1932, he had an opportunity to discuss the matter with Dr. Wattenberg, who suggested that the greater value found in the samples which had been taken under pressure might be ascribed to the fact that on account of the additional pressure the samples had absorbed oxygen rapidly even if the ordinary precautions had been taken when filling the oxygen bottles. This explanation is probably correct, and it is, therefore, probable that the values of the oxygen content obtained at the greater depths at stations 5 and 6 were too high. Since at station 3 the differences between the observed values are nearly constant and on the average 0.22, a correction of –0.22 has been applied to the values of the oxygen content of the samples which were taken at stations 5 and 6 from the water bottles when still under pressure in the diving compartment. This correction brings the values at station 6 nearer to the values at the corresponding depths at stations 1 and 2, but leaves some doubt as to the exact amounts of oxygen in the deep water. The possible error must, however, be small because the applied correction, which cannot be far wrong, amounts to less than 4 per cent of the uncorrected value.

pH-VALUES

The determinations of the pH-values were undertaken by means of Sund's colorimeter, using phenolphthalein as an indicator. The colored solution of the wedge was prepared by mixing solutions of saphranin and borax-methylen blue until a color was obtained which corresponded very closely to the color which sea water attains when adding phenolphthalein. The solution proved to be very constant after sterilizing with $HgCl_2$.

According to Buch [1929] we have for the pH of the water sample *in situ*

$$pH_T = pH_{tb} + 0.010\,(t_b - T) \tag{1}$$

where t_b is the temperature of the buffer, T the temperature *in situ* of the water and pH_{tb} the pH of the buffer at temperature t_b.

Using a wedge, as is the case in Sund's colorimeter, one has to determine the scale value of the wedge by means of a buffer series at a known temperature, t_b, and construct a curve showing the relation between the readings of the instrument and the values of pH_{tb}. When examining water samples one reads off from this curve the pH_{tb} which corresponds to the reading of the colorimeter and this value has to be corrected by means of formula (1).

It follows from formula (1) that if the calibration of the wedge is undertaken at two different temperatures the curves, representing the relation between the readings and the values of pH_{tb}, must be displaced parallel to the axis of pH. Calling the two temperatures of the buffer series t_1 and t_2, we have

$$pH_T = pH_{t1} + 0.01\,(t_1 - T) = pH_{t2} + 0.01\,(t_2 - T)$$

or

$$pH_{t2} = pH_{t1} + 0.01\,(t_1 - t_2)$$

The displacement along the pH-axis is thus equal to $0.01\,(t_1 - t_2)$.

The wedge was calibrated by means of a standard buffer series which was obtained from the Laboratoire Internationale Hydrographique in Copenhagen in May, 1931. Calibrations at a temperature of 18° were undertaken at the Geophysical Institute in Bergen twice (June 1 and July 13) before the departure and once (September 21) after the return of the expedition, and at a temperature of 7° during the expedition (September 3). The resulting curves are reproduced in fig. 7. When constructing the curve at 7° the pH values of the buffers at 18° were corrected by means of the table given by Buch.

It is seen that the two curves at 18° agree very well, indicating that the color of the wedge remained constant from the beginning of June until the end of September. The curve which was obtained during the expedition agrees perfectly with the two others when displaced the distance 0.01 (7–18) = –0.11 parallel to the pH-axis.

A second wedge with a much more diluted solution was also used because by means of this wedge a higher degree of accuracy could be obtained in the interval in which most of the values ranged. This wedge was examined at a temperature of 18° before the departure of the expedition and at a temperature of 5° during the expedition. The two curves which were obtained are shown in fig. 8, from which it is seen that they agree perfectly because they cover each other if the curve at 5° is displaced the distance 0.01 (5–18) = –0.13 parallel to the pH-axis.

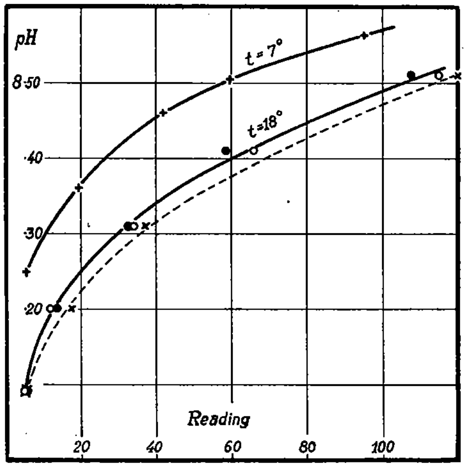

Fig. 7.—Calibration curves of the "strong" pH-wedge at 18° before (full drawn curve) and after (dashed curve) the expedition and at a temperature of 7° on the expedition.

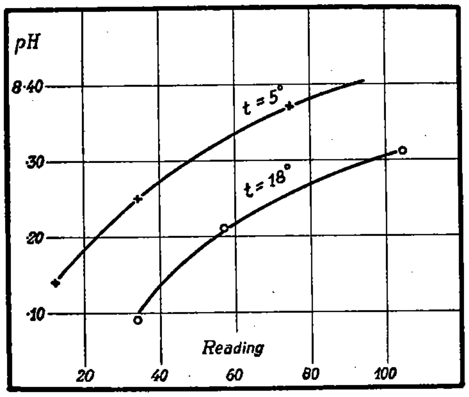

Fig. 8.—Calibration curves of the "weak" pH-wedge at 18° before the expedition and at a temperature of 5° during the expedition.

In order to obtain the pH values of the sea water *in situ* we have, therefore, to find the value of pH_{t_b} which corresponds to the colorimeter reading in question and correct this value by means of formula (1), introducing t_b = 18° if we use the curves which were determined at 18° or t_b = 7° or 5° if we use the curves which were determined at 7 and 5 degrees. The value which is found has finally to be corrected for salt error.

As a rule the pH values were determined a few hours after the samples had been taken from the water bottles, but the water bottles were not emptied before the work in the diving chamber had been completed. Thus they had been hanging full of water for several hours. In most cases 4 to 5 hours elapsed from the moment when the water bottle came up until the pH-value was determined and in a few instances this time difference amounted to about 11 hours. Comparing the observed values from nearly the same depths at different stations, however, we find no effect of this time difference as seen from the following compilation of the extreme cases:

Station	Depth, m.	Time Difference in Hours	Mean pH
1	1060, 1250, 1529	10.7	8.03
2	1080, 1280, 1648	5.8	8.04
2	2110, 2616	6.2	8.07
3	2000, 2500	3.9	8.06
5	200, 400, 522	11.1	8.18
7	200, 400, 580	4.0	8.14

There is no reason for assuming that errors were introduced by letting too long a time elapse between the collection of the water samples and their determination.

Determination of P_2O_5

The phosphates (P_2O_5) were determined by the method of Atkins as modified by Sund, using Sund's colorimeter for measuring the color of the samples. A solution of borax methylen blue was used for comparison and the scale value of the wedge was examined before running each series of samples by adding known quantities of a weak solution of KH_3PO_4 to samples of surface water which contained very small amounts of phosphates themselves. These examinations of the scale value of the wedge showed that the color of the wedge remained unchanged with time and was independent of the temperature. The mean calibration curves as obtained before the departure of the expedition in June and during the expedition are shown in fig. 9. The former was determined at a temperature of 18°, the latter at a temperature of about 5°, but it is seen that they have nearly the same form and can be brought to coincide by a displacement parallel to the P_2O_5-axis. If both curves are so displaced that they run through the origin of the co-ordinate system, they coincide and from that curve the phosphate content corresponding to any reading of the instrument is read off. The greater displacement of the curve which was found in Bergen is caused by the greater phosphate content of the surface water used in Bergen.

Nitrites

The content of nitrite nitrogen was examined by adding a mixture of α-naphthylamine and sulphanilic acid in glacial acetic acid to a water sample of 100 cc. and examining the color of the sample in the colorimeter, using the weak pH-wedge which was used when determining small values of pH.

Determinations of the scale value of the wedge by means of known quantities of KNO_2 in surface water were carried out before the departure of the expedition and during the expedition, the former at a temperature of 18°, the latter at a temperature of 4°. The calibration curves have the same shape, but deviate considerably from each other. The two curves which were obtained are shown in fig. 10, from which it is seen that a NO_2-content of 5 mg/m^3 gave a scale reading of 36 at a temperature of 18°, but a scale reading of 68 at a temperature of 4°. The latter curve represents the results of several calibrations of the wedge which were undertaken at about the same temperature. These gave consistent results, for which reason calibration was omitted at some stations.

TEMPERATURE, SALINITY AND DENSITY

The observed values of temperature and salinity, and the densities (σ_t) which have been computed from these, are given in the Table of Results. The vertical distribution of the same elements and of the percentage saturation of oxygen at the individual stations is represented in figs. 11 to 18. At station 2 the salinity, 34.92 °/oo, at a depth of 784 m. appears to be slightly too low and the curve has been drawn through the point corresponding to 34.94 °/oo.

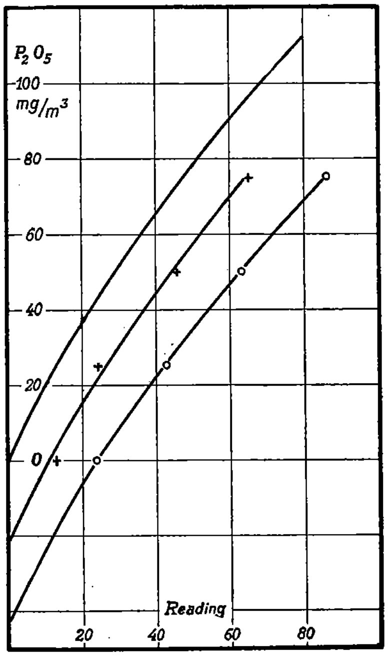

FIG. 9.—Calibration curves of the phosphate wedge before the expedition (lower curve) and on the expedition (middle curve). Upper curve adopted calibration result.

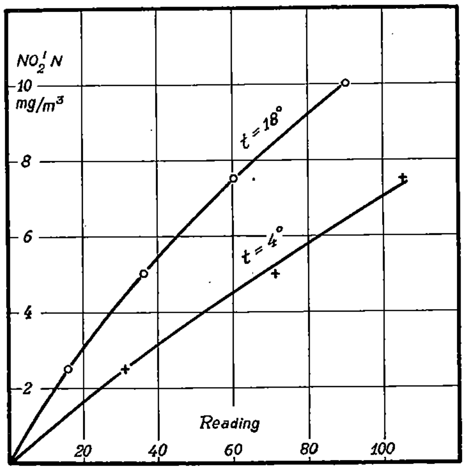

FIG. 10.—Calibration curves of the NO'_2N-wedge at a temperature of 18° before the expedition and at a temperature of 4° on the expedition.

TABLE OF RESULTS.

Physical and Chemical Data of the "Nautilus" Deep-sea Stations, 1931.
Interpolated Temperatures in Parentheses.

DEPTH, METERS	TEMPERATURE (T) °C	SALINITY (S) °/oo	DENSITY (σ_t)	OXYGEN		HYDROGEN ION pH	PHOSPHATE (P_2O_5) mg/m³	NITRITE NITROGEN (NO'_2N) mg/m³
				ml/L	%			
Station 1. August 27, 1931. 81° 52′ N., 13° 40′ E. Bottom 1620 m.								
5	−1.23	..	..	..	..	..	..	..
95	0.11	34.45	27.67	6.77	85	8.16	60	0.1
195	2.08	34.87	27.88	6.57	87	8.11	63	0.0
290	2.13	34.95	27.94	6.87	91	8.06	69	0.0
490	1.71	34.99	28.01	6.71	88	8.12	63	0.0
690	0.33	34.94	28.06	6.46	82	8.11	66	0.0
1060	−0.60	34.93	28.10	6.70	83	8.02	60	0.0
1250	−0.81	34.92	28.10	6.69	82	8.10	71	0.1
1529	−0.91	34.92	28.10	6.50	80	7.99	57	0.0

TABLE OF RESULTS.

Physical and Chemical Data of the "Nautilus" Deep-sea Stations, 1931—Continued.
Interpolated Temperatures in Parentheses.

DEPTH, METERS	TEMPERATURE (T) °C	SALINITY (S) °/oo	DENSITY (σ_t)	OXYGEN		HYDROGEN ION pH	PHOSPHATE (P_2O_5) mg/m^3	NITRITE NITROGEN (NO'_2N) mg/m^3
				ml/L	%			
Station 2. August 28, 1931. 81° 59′ N., 17° 30′ E. Bottom 2655 m.								
5	−1.23	..	..	..	..	..	..	..
50	0.40	34.36	27.59	7.17	90	8.14	47	1.0
100	(2.15)	34.76	27.79	6.76	89	8.06	57	0.0
195	(2.70)	34.97	27.92	6.64	89	8.10	57	0.0
295	2.63	35.00	27.94	6.90	93	8.11	71	0.0
395	2.55	35.02	27.96	6.82	91	8.11	71	0.0
490	2.23	35.01	27.99	6.91	92	8.07	49	0.0
590	1.82	35.00	28.01	6.83	89	8.02	67	0.0
784	0.75	34.92.	28.02	6.84	88	8.04	43	0.0
1142	−0.47	34.92	28.08	..	..	7.94	72	0.0
1330	−0.65	34.92	28.09	6.42	79	8.05	67	0.0
1620	−0.82	34.93	28.11	6.52	80	8.10	69	0.0
2110	−0.91	34.93	28.11	6.58	80	8.05	69	0.0
2616	−0.85	34.93	28.11	6.41	79	8.09	65	0.0
Station 3. August 29, 1931. 81° 51′ N., 21° 30′ E. Bottom 3500 m.								
2000	−0.85	34.93	28.11	6.70	82	8.03	77	..
2500	−0.87	34.94	28.12	6.71	82	8.09	72	..
3000	−0.82	34.94	28.12	6.73	83	8.11	72	..
Station 4. August 30, 1931. 81° 50′ N., 20° 15′ E.								
10	−1.61	31.58	25.42	8.78	103	8.37	32	0.0
25	−1.53	33.65	27.10	9.16	109	8.30	48	0.0
50	−1.71	34.10	27.46	7.66	91	8.18	59	0.0
75	−0.79	34.37	27.66	7.38	90	8.17	67	0.0
100	−0.40	34.42	27.67	7.36	91	8.19	67	0.0
Station 5. September 2, 1931. 81° 38′ N., 24° 45′ E. Bottom 560 m.								
10	2.41	33.39	26.67	7.01	92	8.32	29	0.0
25	3.22	34.04	27.12	7.28	98	8.32	32	0.0
50	..	34.75	27.69	6.95	94	8.24	61	1.8
75	2.87	34.86	27.80	6.84	92	8.20	67	0.8
100	3.15	34.95	27.85	6.67	91	8.22	67	0.0
153	3.43	35.02	27.88	6.70	92	8.22	71	0.0
200	3.16	35.03	27.91	6.99	95	8.19	73	0.0
300	2.85	35.04	27.95	6.96	94	8.20	75	0.0
400	2.56	35.04	27.98	7.01	94	8.15	75	0.0
522	1.80	35.00	28.01	6.95	91	8.21	69	0.0

TABLE OF RESULTS.

Physical and Chemical Data of the "Nautilus" Deep-sea Stations, 1931—Continued. Interpolated Temperatures in Parentheses.

DEPTH, METERS	TEMPERATURE (T) °C	SALINITY (S) °/oo	DENSITY (σ_t)	OXYGEN		HYDROGEN ION pH	PHOSPHATE (P_2O_5) mg/m^3	NITRITE NITROGEN (NO'_2N) mg/m^3
				ml/L	%			
Station 6. September 4, 1931. 81° 40′ N., 11° 20′ E. Bottom 1690 m.								
5	−0.62	31.22	25.10	..	..	..	..	..
25	+0.60	33.99	27.28	8.77	111	8.28	45	..
50	−0.21	34.42	27.66	7.42	92	8.13	64	..
100	+1.48	34.76	27.84	6.98	91	8.08	77	..
200	+2.48	34.97	27.94	6.89	92	8.05	85	..
300	+2.47	34.99	27.95	6.97	93	8.04	82	..
400	..	35.00	27.97	..	..	8.08	88	..
500	+1.83	34.99	28.00	6.92	91	7.91	77	..
680	+0.78	34.95	28.03	7.08	91	8.03	99	..
880	−0.18	34.92	28.07	7.03	88	8.05	93	..
1080	−0.58	34.92	28.09	7.01	87	8.04	100	..
1280	−0.80	34.92	28.10	6.98	86	8.03	83	..
1648	−1.01	34.93	28.12	6.93	85	8.06	87	..
Station 7. September 5, 1931. 81° 24′ N., 6° 50′ E. Bottom 760 m.								
5	−0.51	..	..	..	..	..	..	..
25	0.27	33.69	27.05	8.44	105	8.31	28	0.0
50	0.68	34.49	27.67	7.01	89	8.20	51	2.9
75	1.00	34.64	27.78	7.11	91	8.17	63	4.2
100	2.48	34.93	27.90	6.61	88	8.14	72	0.0
195	3.05	35.06	27.95	..	..	8.14	63	0.0
380	2.39	35.04	27.99	6.94	92	8.16	69	0.0
570	0.68	34.95	28.04	6.95	89	8.13	68	0.0
708	..	34.91	28.07	6.74	85	8.12	66	0.0
750	−0.25	34.92	28.07	5.59	70	8.07	80	0.0
Station 8. September 5, 1931. 81° 01′ N., 4° 15′ E. Bottom 735 m.								
5	−0.95	..	..	..	..	..	..	..
25	−1.51	33.70	27.14	8.45	101	8.24	36	0.0
50	0.29	34.38	27.61	7.13	90	8.19	50	1.4
75	0.90	34.62	27.77	6.90	88	8.13	58	0.0
100	2.71	34.94	27.89	6.76	91	8.09	68	0.0
200	3.24	35.08	27.95	7.02	96	8.10	64	0.0
240	2.72	35.04	27.96	6.90	93	8.11	57	0.0
345	2.41	35.04	27.99	6.34	85	8.11	65	0.0
450	2.11	35.03	28.01	6.72	89	8.12	67	0.0
545	1.35	34.98	28.03	7.07	92	8.09	69	0.0
697	−0.07	34.92	28.07	6.87	86	8.05	69	0.0
Station 9. September 6, 1931. 80° 31′ N., 1° 10′ E. Bottom 3110 m.								
265	1.59	34.93	27.97	6.94	91	8.02	64	..
2600	−0.89	34.93	28.11	6.79	83	7.98	71	..

Figure 19 shows the vertical distribution of temperature, salinity and density at station 98 of the *Quest* which was taken on August 17, 1931, by H. Mosby in latitude 80° 41′ N. and longitude 13° 55′ E. The data from this station have kindly been placed at my disposal by the leader of the expedition, Professor Hans W:son Ahlmann and they are of particular interest when discussing our observations.

Professor Helland-Hansen has kindly let me use the observations of Dr. Devik onboard the *Ringsael* in 1922. These are of great value when examining the character of the Atlantic water entering the Polar Sea and the character of the deep water, but they have not been represented graphically because they were taken in another year and, therefore, are not directly comparable with our values.

a. The Arctic Water. At all stations we find an upper layer of low salinity and mostly also of low temperature. The character of this water is not uniform. Salinity and temperature both vary within wide limits from one station to another and depend partly upon admixture of melting water from the ice, partly upon admixture of Atlantic water and partly upon the cooling in the preceding winter. Our station No. 5, for instance, was taken when surrounded by ice, but in spite of this we found a temperature of 2.41° at a depth of 10 m., and this high temperature must be ascribed to a flow of warm water from the south. The salinity, on the other hand, was only 33.39 ⁰/₀₀ and the low value indicates admixture of melting water. Similar conditions were present at Mosby's station No. 98, but here the water was free of ice and consequently both temperature and salinity near the surface were higher. Intermediate temperature minima, which perhaps indicate traces of the low winter temperatures, were found at stations Nos. 4, 6 and 8. At station No. 4 a temperature of –1.71° was observed at 50 m.

We did not attempt to examine the variations at or very near the surface because we knew these variations to be of purely local character, and this also seems to apply to the conditions in the upper layer in general.

b. The Atlantic Water. The vertical distribution of temperature and salinity has the same character at all stations within the region which was examined. At all stations we find an upper thin layer of low temperature and low salinity, and below this a layer of considerably higher temperature, 2–3°, and high salinity, 34.99–35.08 ⁰/₀₀. This layer represents water of Atlantic origin which has been transported to these latitudes by the branch of the Gulf Stream which passes along the western coast of Spitsbergen. The Atlantic water is found between the approximate depths of 100 and 700 meters, taking temperatures higher than +1.0° and salinities higher than 34.90 ⁰/₀₀ as typical of this water.

On the basis of observations prior to 1912, Helland-Hansen and Nansen [1912] and Nansen [1915] have discussed the Atlantic current off the west coast of Spitsbergen and the character of the Atlantic water penetrating to the north of Spitsbergen. In later years the waters to the north of Spitsbergen have been examined by several expeditions and the entire material of observations is now being worked up at the Geophysical Institute in Bergen.

In this place attention shall only be drawn to the fact that great variations are found in the character of the Atlantic water to the north of Spitsbergen, contrary to the conception of Helland-Hansen and Nansen, who thought that the variations in salinity especially were very small from one year to another. They considered it probable that the salinity of the Atlantic water entering the Polar Basin never exceeds 35.00 to 35.02 ⁰/₀₀ and that the greater part of this water has a salinity between 34.95 and 35.00 °/oo, but their conclusions were partly based on data of small accuracy.

The variation in the character of the Atlantic water can be shown by comparing the mean values of temperature and salinity at 200, 300 and 400 m. as observed at three neighbouring stations in the years 1912, 1922 and 1931, namely Nansen No. 36, August 13–14, 1912, 80° 36′ N., 16° 17′ E.; Devik No. 14, August 25, 1922, 80° 40′ N., 16° 30′ E. and Mosby No. 98, August 17, 1931, 80° 41′ N., 13° 55′ E.

The mean values are:

	St. 36 1912	St. 14 1922	St. 98 1931
Mean temperature 200–400 m.	1.70°	3.70°	3.18°
Mean salinity 200–400 m.	34.90	35.05	35.10

These great variations from year to year shall only be pointed out here. A study of the variations must be based on all available observations and lies outside of the scope of the present paper.

The fact which shall be emphasized here is that from the few older data which have been mentioned here, and from our observations it is evident that, in spite of the variations, the character of the Atlantic water remains unaltered from one year to another and within the entire area to the north and northwest of Spitsbergen. This becomes evident when the temperature-salinity values of the Atlantic water as found by other expeditions and onboard the *Nautilus* are plotted in a temperature-salinity diagram.

Figure 20 shows the corresponding mean temperatures and salinities of the Atlantic water between 200 and 400 m. at four of Nansen's stations of 1912 between latitudes 80° 20′ and 80° 36′ N. and longitudes 10° 04′ and 16° 17′ E., four of Devik's stations of 1922 between latitudes 80° 25′ and 81° 29′ N. and longitudes 16° 30′ and 17° 15′ E., six of our stations of 1931 between latitudes 81° 01′ and 81° 59′ N. and longitudes 4° 15′ and 24° 45′ E. and Mosby's station No. 98 of 1931 in latitude 80° 41′ N. and longitude 13° 55′ E. The temperature-salinity values lie on a straight line and, on the average, an increase in the temperature of 1° corresponds to an increase in the salinity of nearly 0.12 °/oo. Devik's station No. 14 deviates mostly from the line.

From the intimate relationship between the temperature and the salinity of the Atlantic water, it is evident that within the Atlantic water variations in temperature and salinity follow each other both when these variations take place from one year to another or when they are found in one year within different areas.

The uniform character of the Atlantic water becomes still more apparent when, instead of examining the average values from the depths 200 to 400 m., we study the temperature-salinity relations at the different levels. In figs. 21 and 22 the observed values at the above mentioned stations and at the levels 100, 200, 300, 400 and 500 meters have been entered in T-S diagrams. It is seen that at each level a typical T-S relation exists but the position of the line, representing this relation, varies from one level to another. In fig. 23 all lines have been drawn in one diagram in which lines for equal values of σ_t are entered. These lines are very nearly parallel to the lines showing the T-S relations, which means that at a given level the changes in the temperature and salinity of the Atlantic water take place in such way that the density of the water remains unaltered. This again implies that Helland-Hansen's and Ekman's "law of the parallel solenoids" is fulfilled within the area in question.

From the curves and diagrams it is evident that in 1931 the highest temperatures and salinities of the Atlantic water were found near the continental shelf to the north of Spitsbergen and on the ridge to the northwest of the islands. This feature becomes still clearer on comparing the T-S diagrams at the individual stations, which are shown in fig. 24.

Such diagrams are often used in order to check the accuracy of the observations because experience has shown that as a rule the T-S curves for single stations have a smooth form and that irregularities are often due to errors of observation. In our case we only need to point out that the salinity at a depth of 800 meters at station No. 2 appears to be too low as mentioned when dealing with the vertical distribution of the salinity.

The stations have been arranged so that the data from the stations at the greatest distance from the shelf are found in the upper part of the figure and the data from the two stations on the ridge and the two stations near the shelf in the lower part of the figure. The highest temperatures and salinities were found at the *Quest* station No. 98, which has the most southerly position and to which the Atlantic water supposedly has reached by the shortest route. At station No. 5, which also was situated close to the shelf but much further to the northeast, the temperatures and salinities were considerably lower, but the lowest values were met with at the station which was situated at the greatest distances from the shelf, station No. 1. It is thus evident that the temperature and the salinity of the Atlantic water decrease along the shelf and at right angles to the shelf. The latter decrease is more rapid because the distance between stations Nos. *Quest* 98 and *Nautilus* 1 is considerably smaller than the distance between the two stations on the shelf, stations Nos. *Quest* 98 and *Nautilus* 5.

The rapid decrease when proceeding from the shelf is evident from the charts showing the horizontal distribution of temperature and salinity within the Atlantic water at the 100, 200, 300, 400, 500 and 600 meter levels (figs. 25 to 30). The general character of the distribution is the same at all levels, but the contrast between the conditions at the shelf and at great distances from the shelf is most conspicuous at the upper levels.

At all levels the highest temperature and salinity are found near the shelf in the southern part of the area, but high values also occur near the shelf in the northern part and on the ridge to the northwest of Spitsbergen, while the lowest values are present in the central part at the greatest distances from the shelf.

This distribution indicates that the greater part of the Atlantic water follows the border of the shelf towards the northeast, but a weaker branch runs towards the northwest along the ridge. Simultaneously the Atlantic water slowly spreads towards the north as shown by the fact that Atlantic water is present at all stations. The last conclusion is confirmed by a study of the current on the basis of dynamic calculations.

A vertical section (fig. 31), which has been constructed by means of the horizontal charts, clearly shows the spreading to the north of the Atlantic water.

The Deep Water. At our stations we have a total of 14 observations from depths greater than 1000 meters, according to which the temperature of the deep-water decreases from about –0.05° at 1000 meters to about –0.91° between 1500 and 2000 meters. The lowest temperature, –1.01°, was found at station No. 6 at a depth of 1650 m., 40 m. above the bottom.

Below a depth of about 2000 meters the temperature increases towards the bottom as shown by the deepest observations at stations Nos. 2 and 3. The salinity, which has a fairly constant value (slightly above 34.92 ⁰/oo) at depths between 1000 and 1500 meters, also appears to increase towards the bottom in the greatest depths. The exact values of the salinities as computed from the results of the chlorine titrations are:

Station No. 2		Station No. 3		Station No. 6	
Depth, m.	S ⁰/oo	Depth, m.	S ⁰/oo	Depth, m.	S ⁰/oo
2120	34.930	2000	34.934	1280	34.920
2616	.932	2500	.937	1650	.932
		3000	.938		

This increase towards the bottom is also shown by the determinations of the density by means of the hydrometer of total immersion which gave:

Station No. 2	
Depth, m.	σ_0
2120	28.091
2616	.094

In 1922 Dr. Devik obtained 9 observations from depths below 1000 meters. The variation of temperature with depth in the deep-water had the same character as observed onboard the *Nautilus* in 1931. At his deepest station, No. 17, Dr. Devik also found a well defined increase of the temperature towards the bottom, but the salinity appeared to decrease when approaching the bottom, contrary to our results. His salinity values are, however, not as accurate as our values because they were determined by a burette of older construction which could not be read as closely as the new, improved burettes. Furthermore, the decrease of the salinity towards the bottom at depths below 2000 meters is shown by the two determinations at his station No. 17 only, for which reason it seems permissible to regard the result as doubtful. This is even more evident when all observations from depths below 1000 meters are plotted in one diagram because then the salinity appears to increase towards the bottom as observed by us.

In fig. 32 the temperatures and salinities below a depth of 1000 meters as observed in 1922 and in 1931 have been plotted against depth and smooth curves representing temperatures and salinities as functions of depth have been drawn. The mean temperature- and salinity-curves from the two years are very similar in shape, but below 2000 meters the temperature was about 0.05° higher in 1931 than in 1922 and below 1000 meters the salinity was about 0.01 ⁰/oo higher. The increase of salinity towards the bottom is shown indisputably in 1931 and in the opinion of the writer the observations of 1922 do not contradict the presence of such an increase.

On account of this increase the equilibrium near the bottom is stable in spite of the temperature increase being greater than the adiabatic. At a level of 2500 m. the adiabatic gradient is 0.075° per 1000 meters, while the observed gradient in 1922 was 0.115° per 1000 meters and in 1931 0.105° per 1000 meters. The salinity gradient was 0.012 ⁰/oo per 1000 meters in 1922 and 0.0095 ⁰/oo per 1000 meters in 1931. Using these values and computing the stability, E, by means of Th. Hesselberg and H. U. Sverdrup's [1915] tables we obtain:

	Stability at 2500 Meters
1922:	$E = 0.48\ 10^{-8}$
1931:	$E = 0.40\ 10^{-8}$

These numerical values cannot be attributed any great weight because they depend mainly upon the value of the salinity gradient, which is determined with much less accuracy than the temperature gradient. The direct observations in 1931 give a salinity gradient of 0.004 °/oo per 1000 meters, while at 2500 meters our curve gave 0.0095. If we use the former value we obtain $E = -0.03\ 10^{-8}$ or practically indifferent equilibrium. In any case the equilibrium near the bottom appears to be stable or indifferent, and it is very improbable that unstable equilibrium prevails.

Nansen [1902] has previously shown that the temperature in the deep part of the Polar Sea increases towards the bottom and has ascribed this increase to the effect of the heating from the interior of the earth. In our case it is possible that the heating from the interior of the earth is of some importance to the temperatures near the bottom, but the parallel increase of the salinity points in the direction that the origin of the very bottom water differs slightly from the origin of the deep water in general. The deep water, no doubt, is formed by mixing between Atlantic water and Arctic water, and within the water thus formed high temperature must correspond to high salinity and vice versa. The heaviest water sinks to the bottom and it is reasonable to assume that the bottom water with the highest salinity originally was the heaviest water. The oxygen content of the deep water at station No. 3 seems to confirm this opinion. Here we find a remarkably high oxygen content and the values increase slightly with increasing depth. At 2000 meters we find 6.70, at 2500 meters 6.71, and at 3000 meters 6.73 ml/L. If these results are correct we must conclude that the water at 3000 meters is "younger" than the water at the higher levels and that this water has sunk to the bottom because of its greater density.

The Origin of the Deep Water. As to the origin of the deep water in the Polar Basin, Nansen has expressed the opinion that this water is of the same character as the deep water in the northern part of the Norwegian Sea and enters the Polar Basin between Spitsbergen and Greenland, passing over a supposed submarine ridge. Nansen [1902] originally based his opinion on the observations of the *Fram;* but as his values of the salinity of the deep water in the Polar Basin were too high, he assumed the depth of the hypothetical ridge to be about 700 meters below sea level. Later on [1915] he arrived at the result that the salinity of the deep water in the Polar Sea probably is the same as that of the deep water of the Norwegian Sea, but since the deep water of the Polar Basin has a higher temperature (with a minimum of –0.8° to –0.9° C.) than the deep water of the Norwegian Sea where the temperature is –1.1° to –1.2°, he concluded that the two basins probably are separated by a submarine ridge rising to 12–1500 meters below the sea-surface: "A submarine ridge rising to levels of between 1500 and 1200 meters below the sea-surface, and extending continuously from Spitsbergen to Greenland, might be sufficient to prevent the coldest deep-water of the Norwegian Sea, with temperatures below –0.9° C., from running into the Polar Basin." [Nansen 1915, p. 39.]

Nansen's conception is substantiated by our observations because in the deep water to the north of Spitsbergen we find very nearly the temperatures and salinities which were previously found in the deep water in the northwest part of the Norwegian Sea at depths of 12–1500 meters. Fig. 33 shows the temperature and salinity below 500 meters at four of the *Belgica* stations (Nos. 15, 16, 17, 19) [B. Helland-Hansen and E. Koefoed, 1907], in the northern part of the Norwegian Sea and the temperature and salinity at our stations Nos. 1, 2, 3 and 6. Comparing first the temperatures it is seen that the temperatures of the deep water of the Polar Basin are the same as those found between the depths of 1100 and 1500 meters in the Norwegian Sea. The salinities in the deep water of the Polar Basin are nearly the same as those found between the same depths in the Norwegian Sea, but we also note a conspicuous difference between the change of the salinity with depth in the two seas. In the Polar Basin the salinity increases with depth, corresponding to the increasing temperature, but in the Norwegian Sea the salinity decreases with depth. We have previously pointed out that the parallel increases towards the bottom of temperature and salinity in the Polar Basin indicate that the bottom water originates from another level than the deep water in general, and from the curves in fig. 33 it seems justifiable to conclude that the very bottom water originates from the highest level.

From the data which are represented in fig. 33 it thus seems very probable that the deep water of the Polar Basin is of the same character as the water in the northern part of the Norwegian Sea between the levels 1100 and 1500 meters, and we must conclude that the deep water of the Polar Basin comes from the Norwegian Sea and enters the Polar Basin at depths between 1100 and 1500 meters. In some places, therefore, the threshold of the supposed ridge between Spitsbergen and Greenland must be deeper than these levels. The available soundings show that the ridge lies at a depth between 700 and 800 meters within the area between northwestern Spitsbergen and the route of the *Nautilus*. The region in which the deep water enters the Polar Basin must, therefore, be sought to the west of the route of the *Nautilus*.

At our station No. 9 in the northern part of the Norwegian Sea we have only one observation from the deep water, showing a temperature of –0.89° and a salinity of 34.93 °/oo at a depth of 2600 meters, or water of the same properties as the deep water of the Polar Basin. According to the soundings this observation was taken in an isolated deep and it seems that this deep is filled with the characteristic deep water of the Polar Basin.

SALINITY AND DENSITY

By means of Nansen's hydrometer of total immersion the density of six water samples was determined onboard. The uncertainty of the result of one single determination ought not to exceed one unit in the fifth decimal place (see page 29), but the available water sample was somewhat small in one instance, and in this case the error in the determination might have been greater.

The chlorine contents of the same water samples (defined as the grams of chlorine equivalent to the total halides in one kilogram of sea water) were determined at the Geophysical Institute in Bergen directly after the return of the expedition. These values should be expected to agree with the chlorine contents as derived from the observed densities by means of Knudsen's tables, but this is not the case as evident from Table 2.

TABLE 2.—*Chlorine Contents determined by Titration and computed from Observed Density*

STATION No.	DEPTH, m.	σ_0 BY HYDROMETER	Cl FROM DENSITY BY HYDROMETER	Cl FROM TITRATION	DIFFERENCE
1	490	28.143	19.385	19.367	−0.018
1	1060 and 1250	.074	.339	.332	−0.007
1	1529	.089	.348	.327	−0.021
2	1160	.115	.366	.331	−0.035 Small sample
2	2120	.091	.350	.335	−0.015
2	2616	.094	.352	.336	−0.016

The difference between the two values of the chlorine content has the same sign in all cases. It is somewhat large in the one case in which the sample was small and the determination of density, therefore, less accurate than in the other cases. Disregarding this one case we find an average difference of –0.015 at a chlorine content of 19.35.

Thompson and Wirth [1931] have recently undertaken a careful examination of the relation between the density of sea water at zero degrees and the chlorine content, using samples from different oceans, and have found a similar discrepancy, the explanation of which is that the atomic weights of 1900, on which Knudsen's tables are based, are slightly in error. Using the atomic weights of 1930 the discrepancy practically disappeared.

In our case introduction of the atomic weights of 1930 leads to an increase of the observed chlorine contents of 0.011 and the discrepancy is reduced to –0.004. This difference is within the limits of the accuracy of the determinations. There is thus no reason for assuming that the composition of the water of the Polar Basin deviates from the normal composition of sea water.

A corresponding examination of the waters on the North Siberian Shelf [Sverdrup 1929] led to a similar discrepancy between the results of determinations of density and of chlorine content. In the surface layers the difference changed with the seasons and was evidently connected with the processes of freezing which appeared to affect the composition of the water. In the deeper water the difference remained constant throughout the year, but was greater than found above, amounting to –0.023 at a chlorine content of 17.9. Using the atomic weights of 1930 the difference is reduced to –0.013, but, considering the large number of observations upon which it is based, this is still too great to be attributed to errors of determination, for which reason it must be concluded that the composition of the water on the North Siberian Shelf deviates slightly from the normal.

The Currents

In order to obtain a basis for a study of the currents, the dynamic depths of standard isobaric surfaces have been computed and expressed as the differences between the real dynamic depth and the dynamic depth which would have been found in water of 0° C. and 35.00 ‰. The absolute values of the dynamic depths are not exact because at several stations too few observations exist from the upper 100 meters, but below 100 meters a sufficient number of observations are available and below 100 meters the relative values, therefore, are correct. We shall make use of these relative values only and first examine the currents at 100 meters, supposing the current at 600 meters, the greatest depth reached at most stations, to be zero.

The relative elevations of the 100, 200, etc., decibar surfaces above the 600 decibar surface are shown in Table 3, which also gives the corresponding values at the four previously mentioned stations of the *Ringsael* in 1922. Perhaps it is not permissible to combine the observations from 1922 with those of 1931, especially because the temperature and salinity distribution differed somewhat in these two years, but in this case the combination leads to a picture which appears to have a reliable character.

The small charts in figs. 34 and 35 show the relative topography of the 100 and 300 decibar surfaces referred to the 600 decibar surface. At both levels we find approximately the same currents. Between the two *Ringsael* stations, Nos. 14 and 15, a strong current runs towards the ENE., the velocity being about 11 cm/sec. at a depth of 100 meters and about 7 cm/sec. at a depth of 300 meters. This current probably follows the border of

TABLE 3.—*Results of Dynamic Calculations.* $\Delta D_{600}-\Delta D_p$ *in Dynamic Centimeters.* $\Delta D_p=D_p-D'_p$, *where D is the Actual Dynamic Depth of the Isobaric Surface p while* D'_p *is the corresponding Depth at Temperature 0° and Salinity 35 °/oo.*

p d.bar	"NAUTILUS"						"QUEST"	"RINGSAEL"			
	Sta. No. 1 Aug. 27, '31	Sta. No. 2 Aug. 28, '31	Sta. No. 5 Sept. 2, '31	Sta. No. 6 Sept. 4, '31	Sta. No. 7 Sept. 5, '31	Sta. No. 8 Sept. 5, '31	Sta. No. 98 Aug. 17, '31	Sta. No. 14 Aug. 25, '22	Sta. No. 15 Aug. 25, '22	Sta. No. 16 Aug. 26, '22	Sta. No. 17 Aug. 26, '22
	81° 52′ N 13° 20′ E	81° 59′ N 17° 30′ E	81° 38′ N 24° 45′ E	81° 40′ N 11° 20′ E	81° 24′ N 6° 50′ E	81° 01′ N 4° 15′ E	80° 41′ N 13° 55′ E	80° 40′ N 16° 30′ E	81° 00′ N 16° 30′ E	81° 13′ N 17° 15′ E	81° 29′ N 17° 15′ E
100	10.1	9.7	9.2	8.8	7.6	7.9	8.0	12.9	9.1	8.1	9.7
200	6.6	7.2	6.8	6.6	5.5	5.7	5.9	9.8	6.7	5.8	7.0
300	4.4	5.1	4.8	4.7	3.8	4.1	4.2	7.0	4.6	4.0	4.8
400	2.5	3.1	2.8	2.9	2.2	2.5	2.5	4.4	2.8	3.4	2.8
500	1.0	1.4	1.2	1.3	0.9	1.1	1.1	2.1	1.3	1.1	1.3
600	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
800	− 1.4	−2.2	..	−1.8	..	..	..	..	−2.0	−1.6	−1.7
1000	− 2.1	−3.5	..	−2.7	..	..	..	..	−3.0	−2.4	−2.3
1200	− 2.3	−4.2	..	−3.0	..	..	..	..	−3.3	−2.8	−2.4
1400	− 2.1	−4.4	..	−2.7	..	..	..	..	−3.2	−2.8	−2.1
1600	− 1.8	−4.3	..	−2.1	..	..	..	..	−2.8	−2.5	−1.9

the Continental Shelf. In the region to the northwest of the continental shelf the current appears to branch off and the water appears to flow towards the W., with a velocity which is about 2.5 cm/sec. at 100 meters, and about 1.5 cm/sec. at 300 meters.

To the NW. of the continental shelf we have several stations at which the observations reach to depths much greater than 600 meters and there it seems more correct to examine the currents relative to a depth greater than 600. Selecting the 1600 decibar surface as the reference surface, we derive the relative elevations from Table 3. Figs. 36, 37 and 38 give the topography of the 100, 300 and 600 decibar surfaces relative to the 1600 decibar surface. It is seen that at all levels we find a current which flows more or less regularly away from the shelf towards NNW. with a velocity of 1 to 4 cm/sec.

On the basis of these results it cannot be doubted that part of the Atlantic water which enters the Polar Basin follows the continental shelf to the north of Spitsbergen towards the NE., while part of the water slowly spreads towards the NW. Fig. 39 has been prepared in order to give a schematic illustration of this current system. The currents in the vicinity of Spitsbergen are shown as drawn by Nansen [1915] and his representation, which reaches only to a latitude of 80° 40′, has been supplemented by the results from the *Ringsael* in 1922, and our results from higher latitudes. The velocities which are indicated are partly taken from Nansen's chart and partly derived from the observations which have been treated here.

Figure 39 shows the flow of the water at a depth of 100 meters, but it is probable that the flow of the water down to a depth of about 600 meters takes place in the same directions. The average velocities are, however, smaller, and it seems probable that the Atlantic water spreads towards the NW. with an average velocity of about 2 cm/sec.

Our data are insufficient for a study of the flow of the deep water, but they do not contradict the conception that the deep water enters the Polar Basin in the most western part of the region in question, follows the shelf towards the east, and spreads towards the north.

Eddy Convectivity

We have previously drawn attention to the fact that the T-S curves have the same form at the stations in the northeastern part of our area and have pointed out that at each level we find a well-defined relation between temperature and salinity. From this feature we conclude that the flow of the water takes place in a horizontal direction and that changes of temperature and salinity at a given depth result from admixture of water from other depths or, in other words, that they are the result of the eddy convectivity.

I. P. Jacobsen has shown that the coefficient of eddy convectivity can be computed from T-S curves if observations are available from several localities within a known stationary current. Let the curves I and II in fig. 40 present two T-S curves at two localities lying on the same line ~~and~~ of flow within a stationary current, flowing from I to II. The marks on these two curves represent the depth at which observations were taken. A tangent to curve II has been drawn through the point where the curve has its maximum curvature, and this tangent intersects curve I in two points for which the difference in depth shall be called s. According to Jacobsen we then have

$$A = \frac{\rho}{8t} s^2$$

where ρ is the density of water and t represents the time used by the water for covering the distance I to II.

In our case, combining the data from *Nautilus* station No. 5 and *Quest* station No. 98, we can obtain a T-S curve which is characteristic for the conditions near the shelf and, combining the data from stations Nos. 1, 2 and 6, obtain a corresponding curve showing the conditions at a distance of about 110 km. from the shelf. These two T-S curves are plotted in fig. 41. It is evident that the conditions do not correspond to those under which Jacobsen's formula is exactly valid, and, therefore, we cannot expect to find a very accurate value of the eddy convectivity; but we can probably obtain a value of the correct order of magnitude.

Assuming the average velocity of the current to be 2 cm./sec. we find $t = 55 \times 10^5$ sec., and from the figure we find $s = 440 \times 10^4$ cm. With these values and $\rho = 1.03$ we obtain

$$A = 44 \text{ gr. cm.}^{-1} \text{ sec.}^{-1}.$$

Since the currents can be regarded as horizontal, we can also compute the coefficient of eddy convectivity by means of the formula:

$$\frac{\Delta n}{\Delta t} = A\left(\frac{\partial^2 n}{\partial z^2}\right)_m$$

where Δn means the change in temperature or salinity between two points on one line of flow, Δt the time used by one particle to cover the distance between the two points and $\left(\frac{\partial^2 n}{\partial z^2}\right)_m$ the average value of $\frac{\partial^2 n}{\partial z^2}$ over this distance. Combining the data from stations Nos. 5 and 98 and from stations Nos. 1, 2 and 6 we find:

	$10^8 \frac{\partial^2 T}{\partial z^2}$	$10^8\left(\frac{\partial^2 T}{\partial z^2}\right)_m$	$10^9 \frac{\partial^2 S}{\partial z^2}$	$10^9\left(\frac{\partial^2 S}{\partial z^2}\right)_m$	ΔT	ΔS
At 200 Meters:						
Near the shelf	. .	. .	−0.45	. .	. .	. .
	. .	−0.45	. .	−0.8	−0.71	−0.14
110 km. from the shelf . .	−0.45	. .	−1.10	. .	. .	. .
At 400 Meters:						
Near the shelf	−0.33	. .	−0.34	. .	. .	. .
	. .	−0.33	. .	−0.3	−0.42	−0.06
110 km. from the shelf . .	−0.33	. .	−0.27	. .	. .	. .

Assuming the average velocity to be 2 cm./sec. we obtain:

At 200 meters: . . . . $A = 29$ or 31 gr. cm.$^{-1}$ sec.$^{-1}$.
At 400 meters: . . . . $A = 23$ or 36 gr. cm.$^{-1}$ sec.$^{-1}$.

From station 98 to station 5 the change in temperature at 400 meters is −0.30° and in salinity −0.04 ‰. The distance between the stations is about 170 km. and the average velocity can, allowing for bends in the current, be regarded as about 8 cm/sec. These values, together with the above mentioned values for $\frac{\partial^2 T}{\partial z^2}$ and $\frac{\partial^2 S}{\partial z^2}$ at 400 meters near the shelf give:

At 400 meters: . . . . $A = 34$ or 50 gr. cm.$^{-1}$ sec.$^{-1}$.

These different values are in good agreement but this may be accidental because it is impossible to determine the quantities involved with any appreciable degree of accuracy, but since both methods give nearly the same result, we may regard the order of magnitude of A as correct and conclude that A lies between 20 and 50 gr. $cm.^{-1}$ $sec.^{-1}$.

The stability of the Atlantic water is not very great. Using the same tables as above (page 44) for computing the stability we find between 200 and 500 meters nearly the same value at all stations and on the average $E = 24 \times 10^{-8}$. Considering this small stability and the fact that strong tidal currents are present besides the average currents which we have computed [Nansen 1915] a coefficient of eddy convectivity between 20 and 50 appears to be small. It is probably smaller than the corresponding coefficient of eddy viscosity for which values of about 20 have been found only where the stability was very great. Our values, on the other hand, are in good agreement with the value of 20 c.g.s. units which Fjeldstad [Helland-Hansen 1930] has found for the coefficient of eddy convectivity on the basis of the annual variation of temperature in the upper layers of the North Atlantic Ocean and the values 30 to 40 c.g.s. units which McEwen [1918] has derived from observations off the coast of California. Our results, therefore, at least do not contradict the conclusion of Helland-Hansen [1930] that in the sea the coefficients of eddy convectivity and eddy viscosity are materially different.

Oxygen, pH, Phosphates and Nitrites

The vertical distribution of oxygen content, percentage of oxygen saturation, pH and phosphate content is shown for the single stations in the graphs, figs. 11 to 18. The nitrite content has not been represented because at many stations no nitrite was found. An examination of the curves shows that the absolute values and the variations with depth of the elements with which we are dealing are typically different within the three previously studied layers of water, the Arctic water, the Atlantic water and the deep water.

The Arctic Water. In the Arctic water the oxygen content shows, somewhat below the surface, a maximum which is characteristic of the photosynthetic zone. At the stations from which observations at a sufficient number of levels are available this maximum appears to lie between 10 and 25 meters, and as a rule the water is considerably supersaturated there. The absolute highest value for oxygen content, 9.16 ml/L, was found at station No. 4 at 25 meters but the greatest supersaturation, 111 per cent, was reached at station No. 6, also at 25 meters. At station No. 5, at which high temperatures were found in the Arctic water, the maximum is poorly developed and saturation is not reached.

At all stations the pH value is highest near the surface where values greater than 8.3 are found. It appears to decrease slowly in the upper 25 meters and more rapidly below that depth.

The phosphate content is small near the surface but increases rapidly down to 50 meters.

Nitrite nitrogen is present at the lower levels in the Arctic water. No traces of nitrite nitrogen were found above a depth of 50 meters but at 50 meters four out of five samples showed a small content of nitrite nitrogen. At 75 meters two out of four samples and at 100 meters one out of six samples showed nitrites. Below 100 meters only one sample from 1250 meters at station No. 5 showed a trace of nitrite nitrogen, and this trace was so small that one can safely state that below 100 meters the content of nitrite nitrogen is negligible, and that nitrite nitrogen is found only within the lower part of the Arctic water and about 50 m. below the photosynthetic zone. This result is in agreement with the results of Atkins [1930], who showed that nitrite nitrogen generally occurs in intermediate layers.

We obtain a qualitative picture of the distribution of oxygen, pH-values, phosphates and nitrites in the Arctic water by computing mean values at the different levels, using all available observations at each level. These mean values are given in Table 4.

TABLE 4.—*Mean Values of Oxygen Content, Percentage Saturation, pH, Phosphate, and Nitrite Nitrogen Content in the Arctic Water.*

DEPTH METERS	NUMBER OF OBSERVATIONS	O_2 ml/L	O_2 %	pH	P_2O_5 mg/m^3	NO'_2 N mg/m^3
10	2	7.90	98	8.34	30	0.0
25	5	8.42	105	8.29	38	0.0
50	6	7.22	91	8.18	55	1.4
75	4	7.06	90	8.17	64	1.2
100	7	6.84	89	8.13	67	0.0

It cannot be claimed that the table shows the correct average values at the time of observations because the number of stations is small and at several levels observations were made at a few of these stations only. The table, however, undoubtedly gives a correct picture of the typical variations with depth within the Arctic water. As to the phosphate value at the surface it may be mentioned that in connection with the calibration of the wedge in the colorimeter (page 31) this was found to be 22 mg/m^3 and that this value agrees well with the value at 10 meters, 30 mg/m^3, which is based on two determinations only.

THE ATLANTIC WATER. Within the Atlantic water at all stations except No. 8 we find a minimum of oxygen in the upper part and a maximum in the middle or lower part. The minima and maxima are present both in the oxygen content and in the percentage saturation. At station No. 8 we find the upper minimum but the maximum is split up in two parts which are separated by a minimum. It is possible that this feature, which is too pronounced to be due to errors of observation, is connected with the somewhat unusual stratification within the Atlantic water at this station. From the distribution of temperature and salinity it appears as if the Atlantic water at this station consisted of two separate bodies of water, one upper of high temperature and high salinity and one lower of lower temperature and lower salinity. The peculiar distribution of oxygen indicates that within each of these bodies of water we find a minimum of oxygen in the upper part and a maximum in the lower part.

The pH-value decreases more or less irregularly with increasing depth and on the average is 8.15 at a depth of 100 meters and 8.09 at a depth of 500 meters.

The phosphate content varies unsystematically with depth, the average value between 100 and 500 meters being 69 mg/m^3. Nitrite nitrogen is not present. Mean values at the depths 100 to 500 m., based on observations at stations Nos. 1, 2, 5, 6 and 7 are given in Table 5.

The values at 100 meters do not agree exactly with those in Table 4, because they are derived from different observations.

TABLE 5.—*Mean Values of Oxygen Content, Percentage Saturation, pH, and Phosphate Content in the Atlantic Water*

DEPTH METERS	NUMBER OF OBSERVATIONS	O_2 ml/L	O_2%	pH	P_2O_5 mg/m^3
100	5	6.74	89	8.15	67
200	5	6.70	90	8.13	68
300	5	6.87	92	8.11	73
400	5	6.85	92	8.09	74
500	5	6.84	90	8.09	66

THE DEEP WATER. The oxygen content appears to be nearly constant below a depth of 1000 meters, although the observations at station No. 3 indicate a small increase towards the bottom in the greatest depths.

The pH-values and the phosphate content vary irregularly both with depth and from one station to another. The greatest phosphate content was found at station No. 6 at depths between 600 and 1100 meters. For some reason these values seem to be too high because they reach 100 mg/m^3, while at all other stations the values range between 60 and 75. The high values have, however, been included in the means because it has been impossible to find any errors of determination.

From all observations below a depth of 500 m. we obtain the mean values in Table 6, excluding the value of the oxygen content at 750 meters at station No. 7, which deviates so much from other values in the same depth that some error must have been made.

TABLE 6.—*Mean Values of Oxygen Content, Percentage Saturation, pH, and Phosphate Content below 500 Meters*

INTERVAL OF DEPTH METERS	NUMBER OF OBSERVATIONS	MEAN DEPTH METERS	O_2 ml/L	O_2%	pH	P_2O_5 mg/m^3
500 to 1000	11	650	8.82	87	8.07	71
1000 to 1500	3	1190	8.58	81	8.05	71
1500 to 2000	6	1600	8.66*	82*	8.03	75
2000 or more	5	2450	8.62	81	8.07	71

*5 observations of oxygen.

By means of the data in Tables 4, 5 and 6 the curves in fig. 42 have been constructed and these curves probably give a fairly correct picture of the average conditions in the waters to the north of Spitsbergen. The oxygen content and the percentage saturation are shown in two sections, figs. 43 and 44.

We have not taken the one deep-water observation in the northern part of the Norwegian Sea (Station No. 9) into account, but this observation at a depth of 2600 meters gave very nearly the value which we have found at the corresponding depth in the Polar Sea. At station No. 9 the oxygen content appears to be somewhat greater and the pH-value somewhat smaller than in the Polar Sea, but the differences are practically within the limits of the accuracy of the observations.

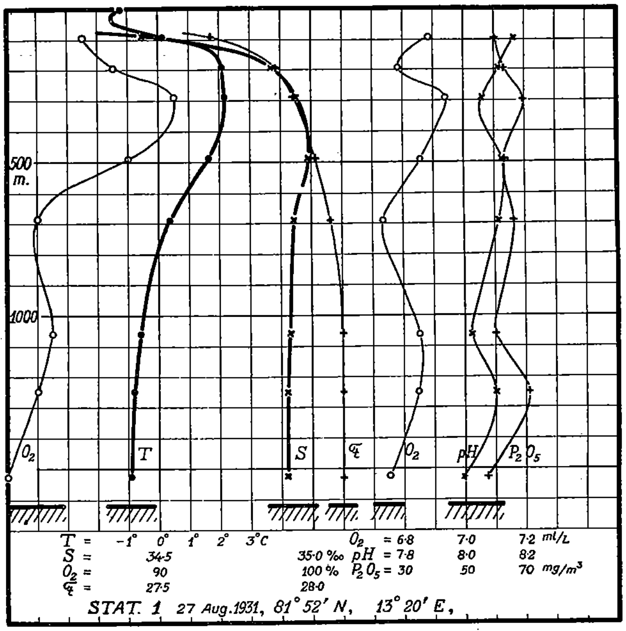

FIG. 11.—Vertical distribution of observed elements at station No. 1

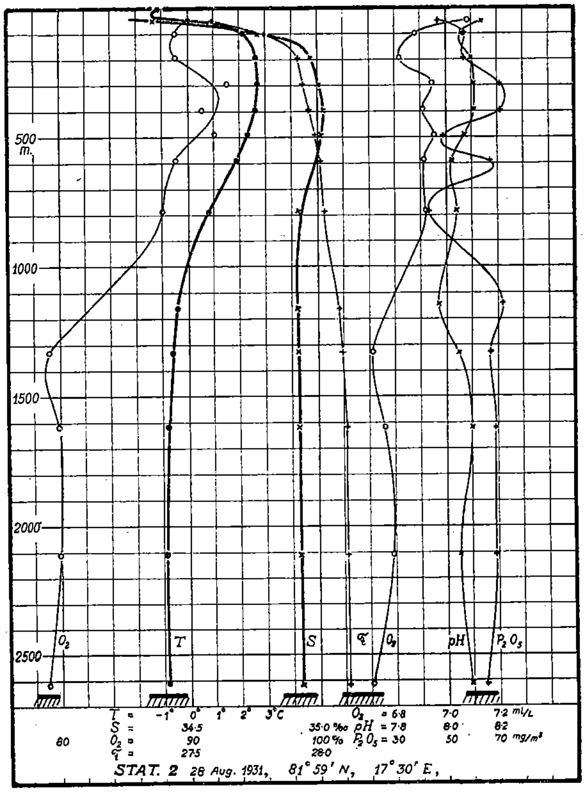

FIG. 12.—Vertical distribution of observed elements at station No. 2

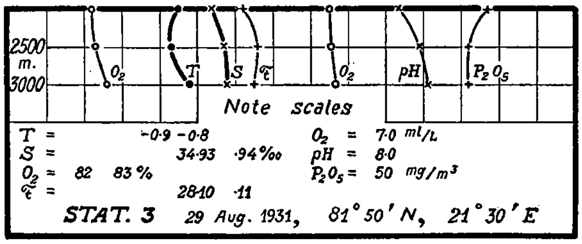

FIG. 13.—Vertical distribution of observed elements at station No. 3

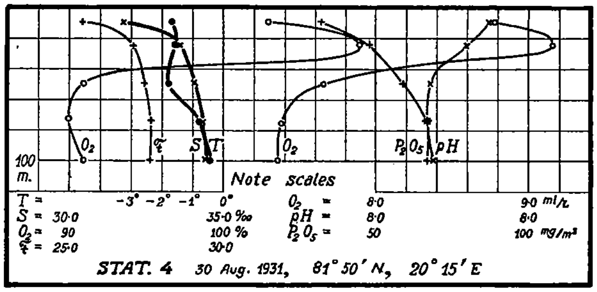

FIG. 14.—Vertical distribution of observed elements at station No. 4

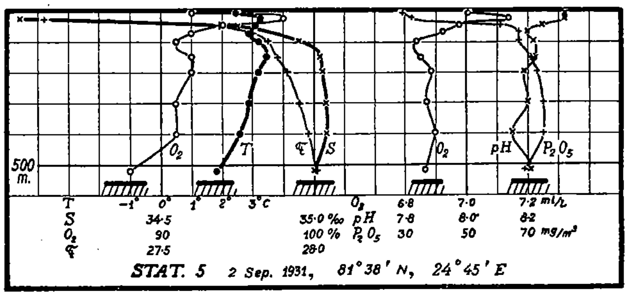

FIG. 15.—Vertical distribution of observed elements at station No. 5

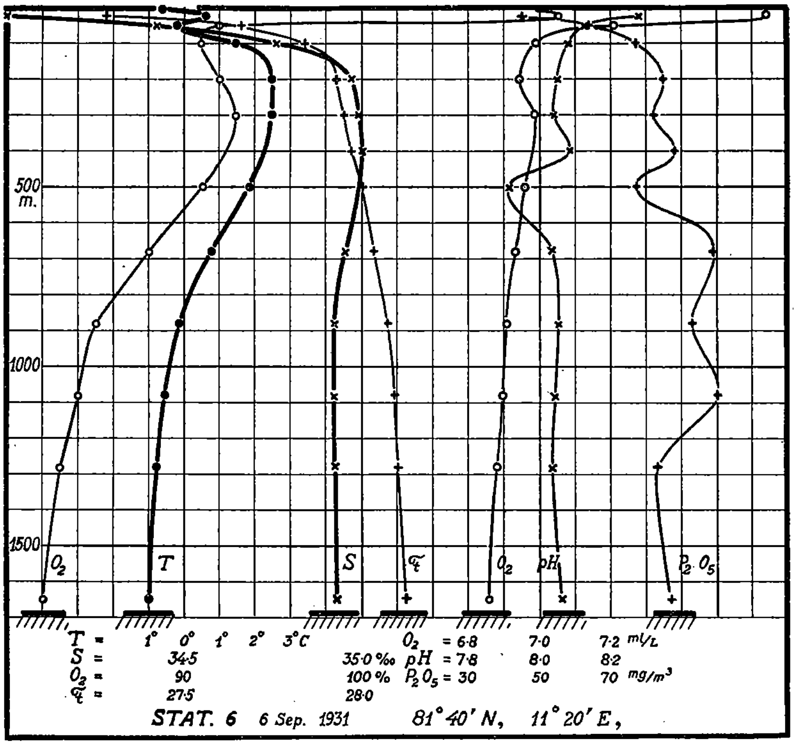

Fig. 16.—Vertical distribution of observed elements at station No. 6

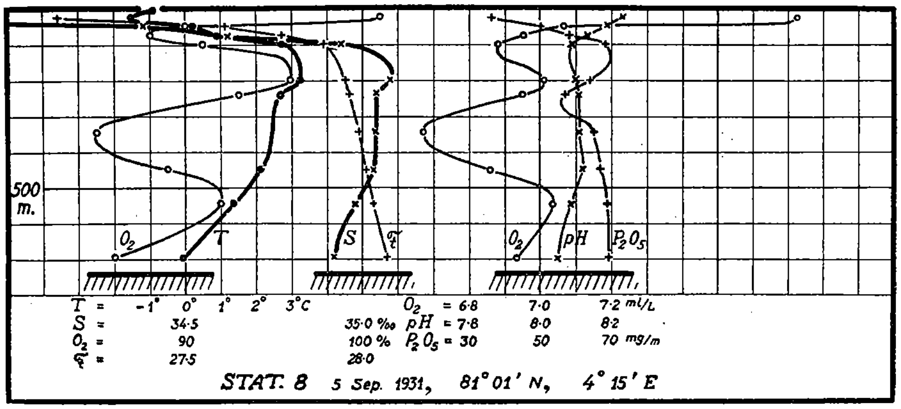

Fig. 17.—Vertical distribution of observed elements at station No. 7

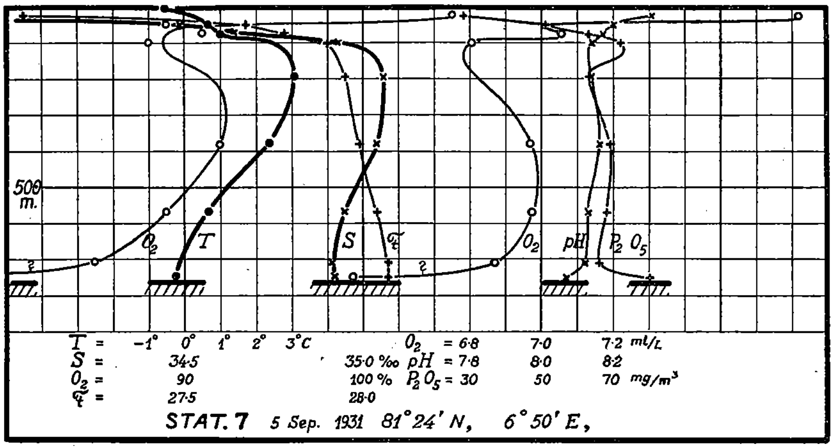

FIG. 18.—Vertical distribution of observed elements at station No. 8

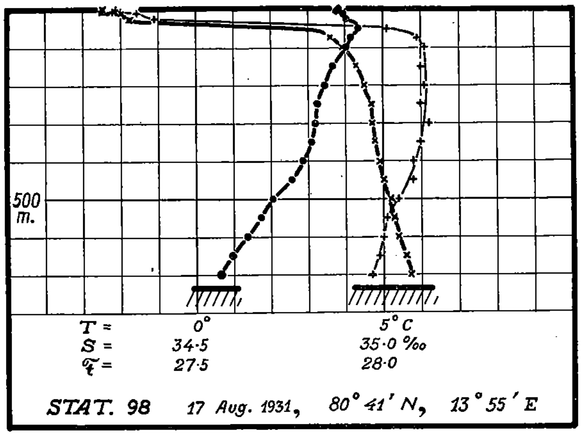

FIG. 19.—Vertical distribution of temperature and salinity at *Quest* station No. 98

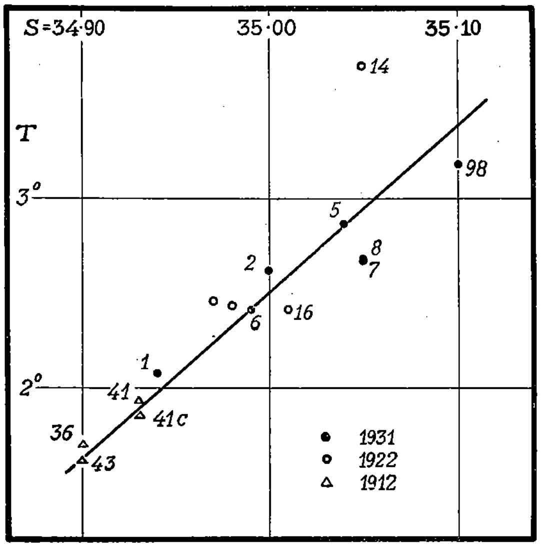

FIG. 20.—Relation between the mean temperature and salinity of the Atlantic water between 200 and 400 meters at stations to the north of Spitsbergen

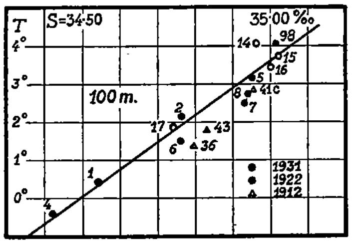

FIG. 21.—Temperature-salinity relation at 100 meters at stations to the north of Spitsbergen

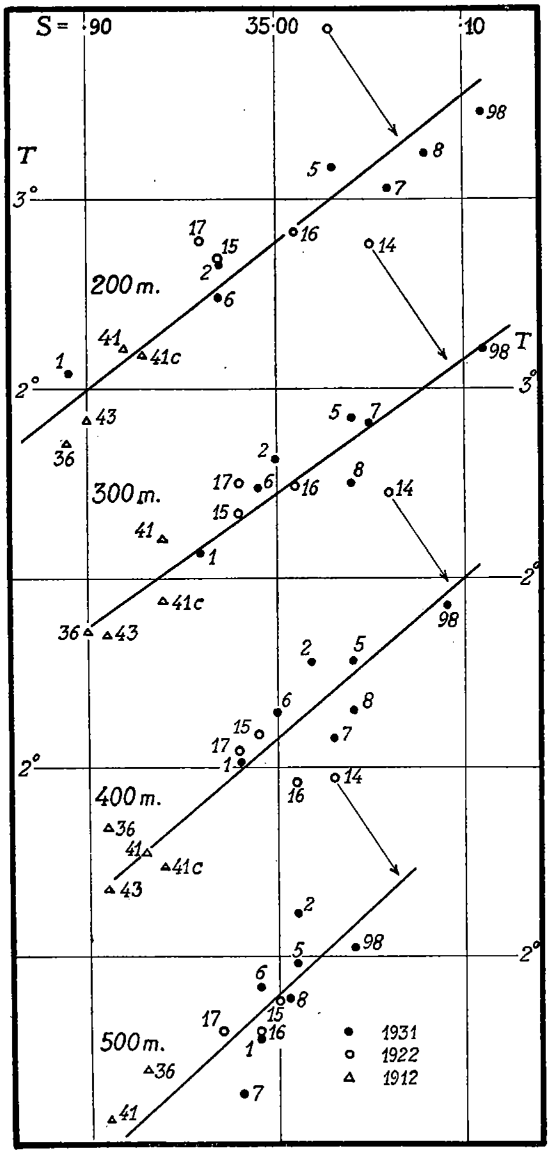

FIG. 22.—Temperature-salinity relations at 200, 300, 400 and 500 meters at stations to the north of Spitsbergen

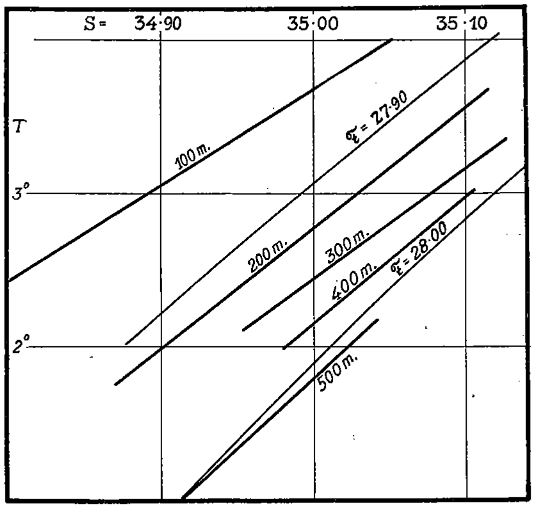

FIG. 23.—Temperature-salinity relations at 100, 200, 300, 400 and 500 meters to the north of Spitsbergen

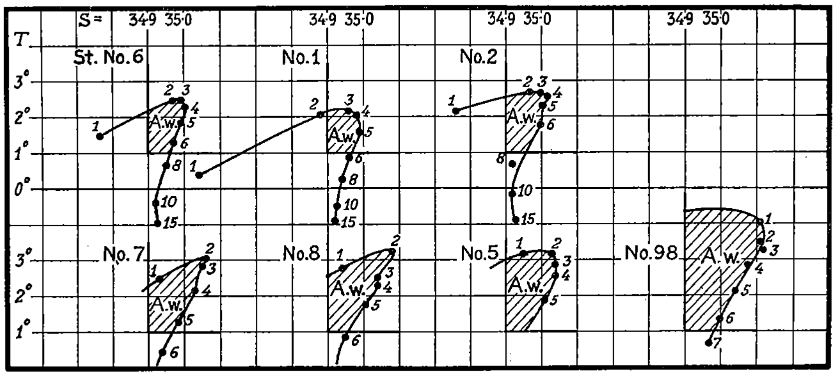

FIG. 24.—Temperature-salinity curves at the individual stations

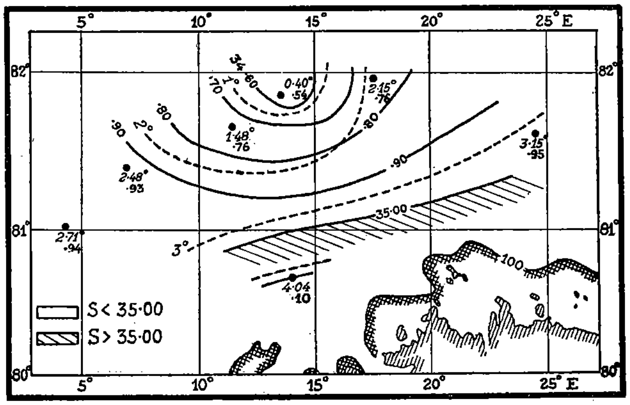

FIG. 25.—Temperature and salinity at 100 meters

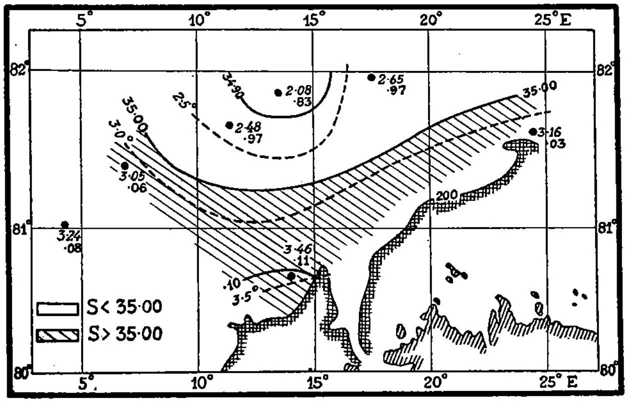

FIG. 26.—Temperature and salinity at 200 meters

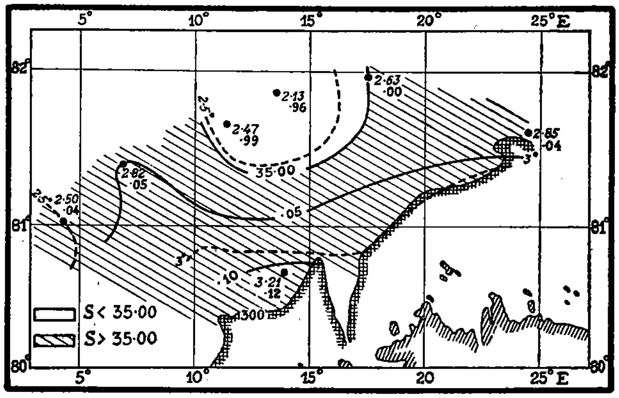

FIG. 27.—Temperature and salinity at 300 meters

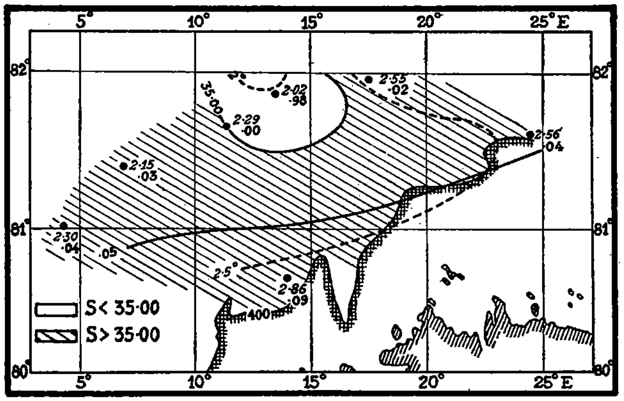

FIG. 28.—Temperature and salinity at 400 meters

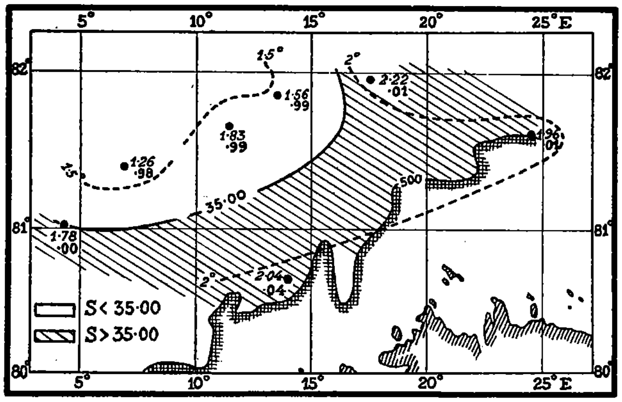

FIG. 29.—Temperature and salinity at 500 meters

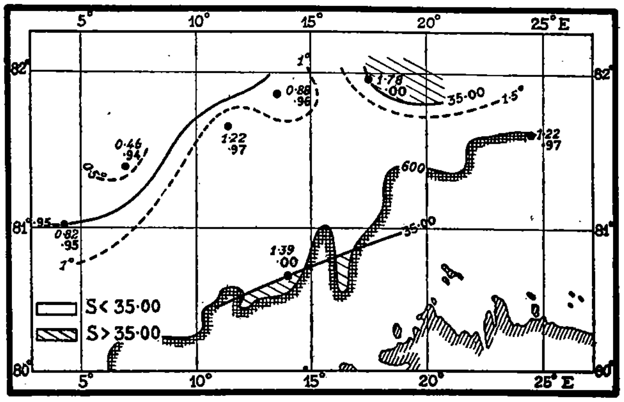

FIG. 30.—Temperature and salinity at 600 meters

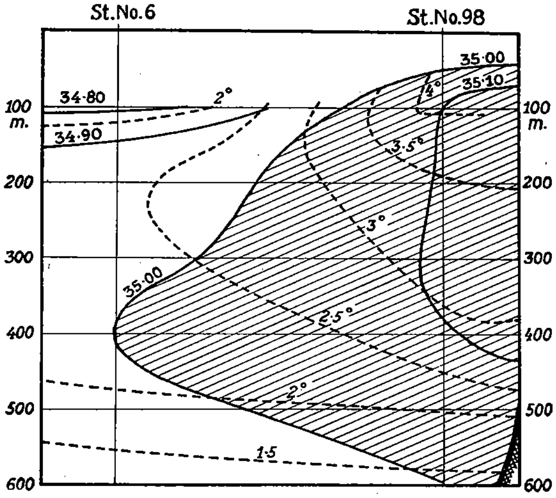

FIG. 31.—Temperature and salinity section at right angles to the shelf

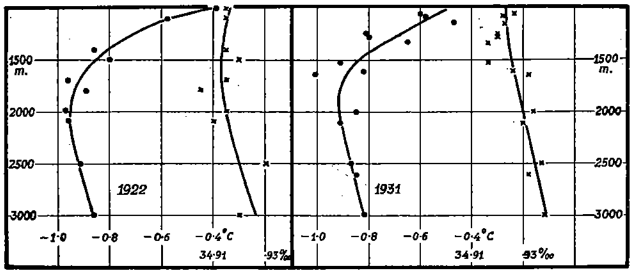

FIG. 32.—Temperatures (·) and salinities (x) below 1000 meters according to observations in 1922 and in 1931

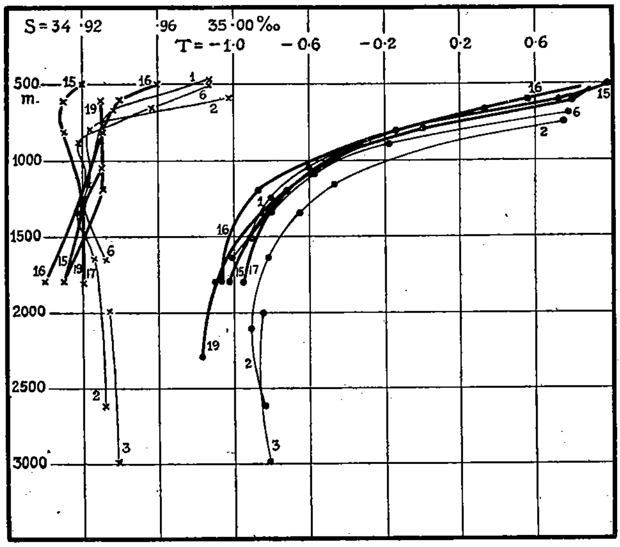

FIG. 33.—Temperatures (·) and salinities (x) below 500 meters in the northern part of the Norwegian Sea (heavy curves) and in the Polar Basin (thin curves)

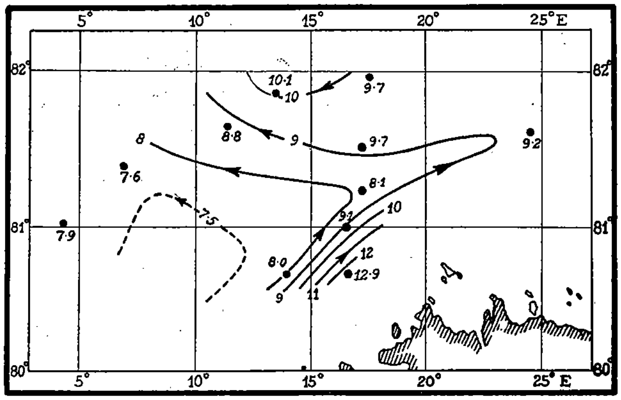

FIG. 34.—Topography of the 100 decibar surface relative to the 600 decibar surface. Relative elevations in dynamic centimeters

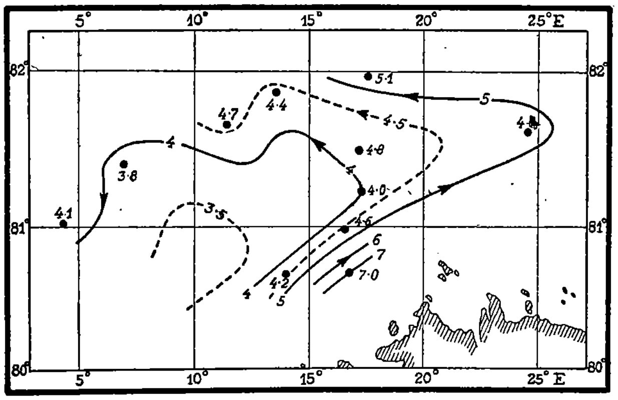

Fig. 35.—Topography of the 300 decibar surface relative to the 600 decibar surface. Relative elevations in dynamic centimeters.

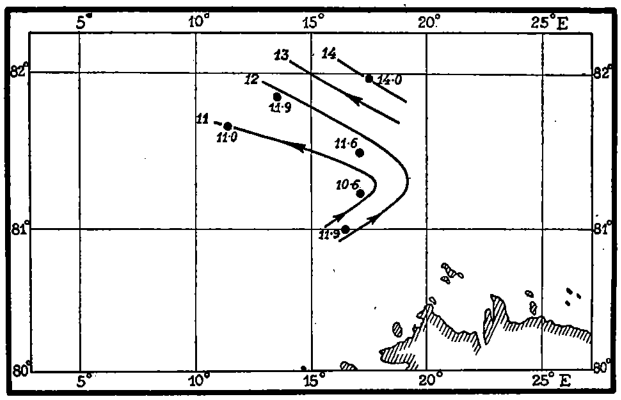

Fig. 36.—Topography of the 100 decibar surface relative to the 1600 decibar surface. Relative elevations in dynamic centimeters.

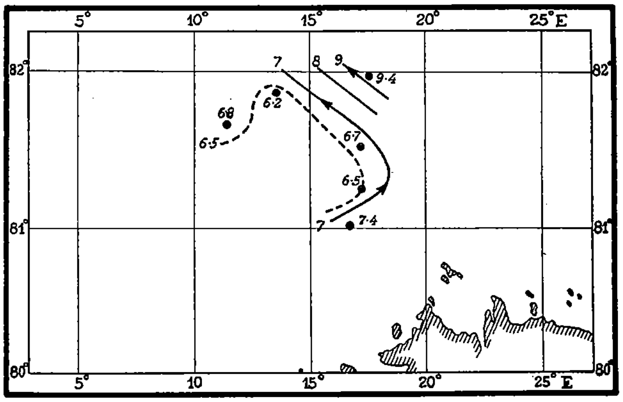

Fig. 37.—Topography of the 300 decibar surface relative to the 1600 decibar surface. Relative elevations in dynamic centimeters.

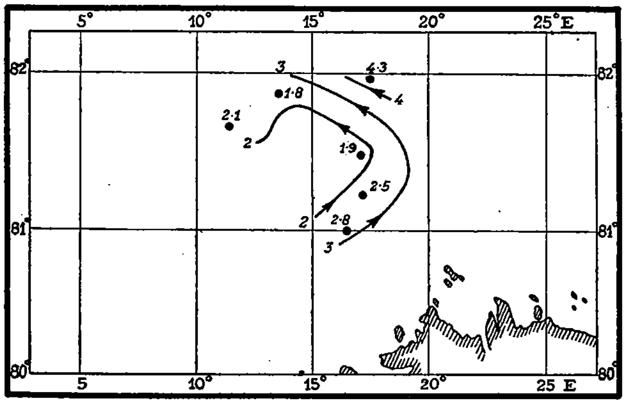

Fig. 38.—Topography of the 600 decibar surface relative to the 1600 decibar surface. Relative elevations in dynamic centimeters.

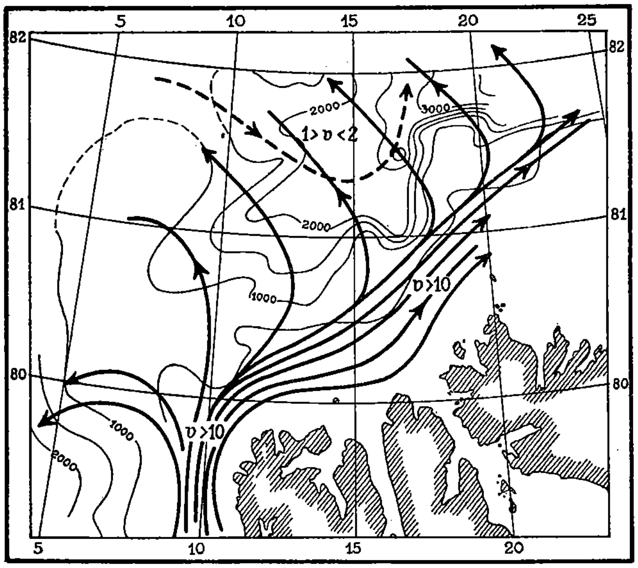

Fig. 39.—Schematic representation of the flow of the Atlantic water to the north of Spitsbergen

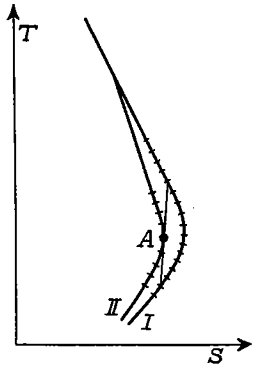

Fig. 40—Jacobsen's method of computing the coefficient of eddy convectivity

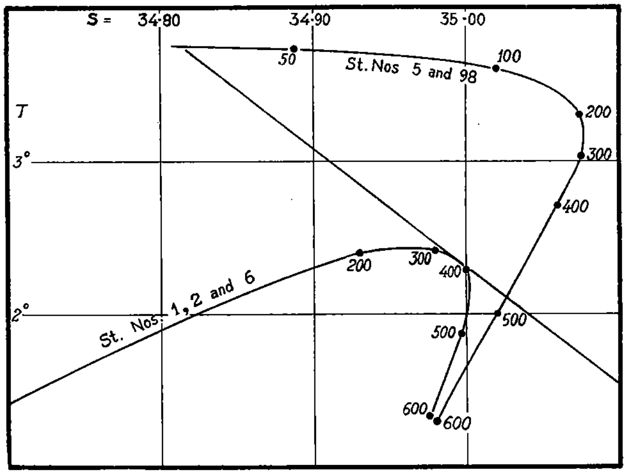

FIG. 41.—T-S curves for computing the coefficient of eddy convectivity

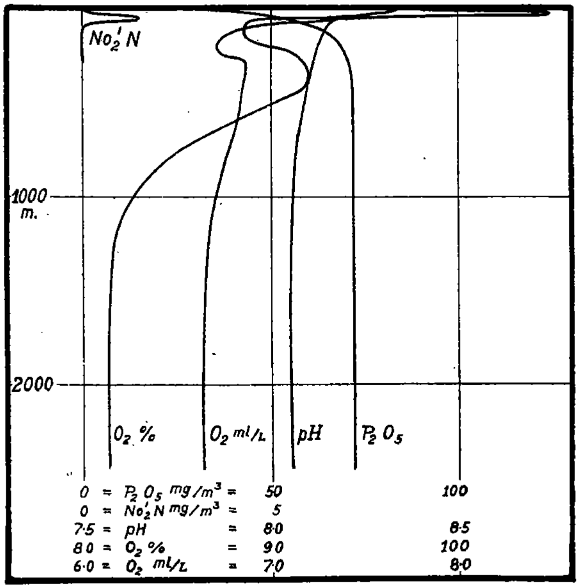

FIG. 42.—Average vertical distribution of oxygen, pH, phosphates and nitrite nitrogen

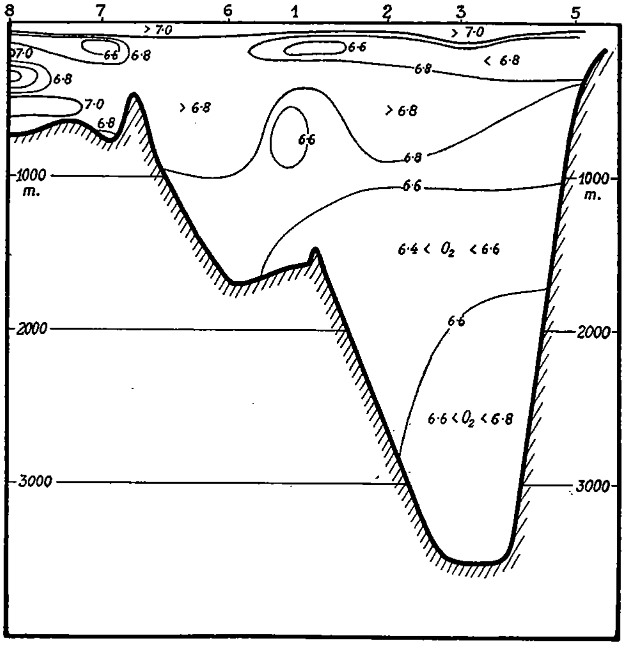

FIG. 43.—Vertical section showing the oxygen content in ml/L at the *Nautilus* stations

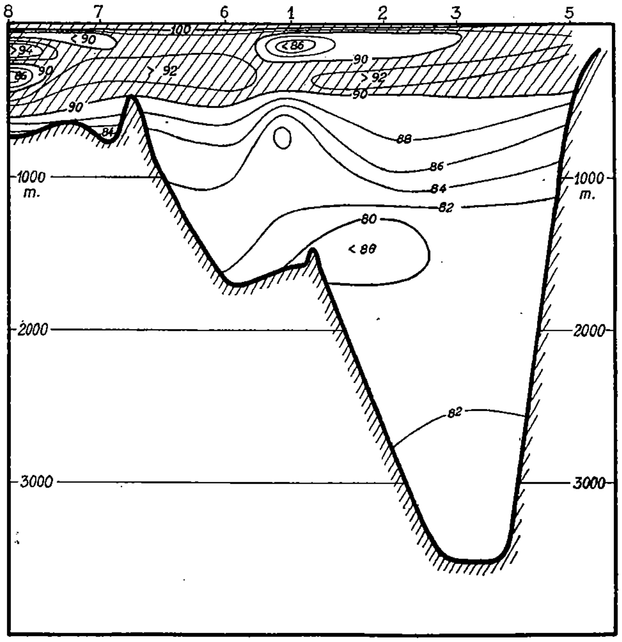

FIG. 44.—Vertical section showing the percentage saturation of oxygen at the *Nautilus* stations

LITERATURE

1930. ATKINS, W. R. G.: Seasonal Changes in the Nitrite Content of Sea Water. Journ. Mar. Biol. Assoc. Vol. XVI, No. 2. P. 515-518.

1927. BÖHNECKE, G.: Die Änderungen des Nullpunktes usw. Veröff. d. Inst. für Meereskunde, A. No. 17. P. 47-55.

1930. HELLAND-HANSEN, B.: Physical Oceanography and Meteorology. Report of the Scientific Results of the "Michael Sars" North Atlantic Deep-Sea Exped. 1910. Vol. I. 217 pp. Bergen 1930.

1907. HELLAND-HANSEN, B. and KOEFOED, E.: Hydrographie, Duc D'Orléans Croisière Oceanographique dans la Mer du Grönland, 1905. P. 275-343, pl. 61-74. Bruxelles 1907.

1912. HELLAND-HANSEN, B. and NANSEN, F.: The Sea West of Spitsbergen. Vid. Selsk. Skrifter. Mat-naturv. kl. 1912. II. No. 12. 89 pp., pl. 1-4. Christiania 1912.

1915. HESSELBERG, TH. and SVERDRUP, H. U.: Die Stabilitätsverhältnisse des Seewassers bei vertikalen Verschiebungen. Bergens Museums Aarbok, 1914–15, No. 15, 16 pp. Bergen 1915.

1907. KRÜMMEL, O.: Handbuch der Ozeanographie. Bd. I, 11+526 pp. Stuttgart 1907.

1918. McEWEN, G.: Ocean temperatures etc. Misc. Stud. Agric. Biol., Semic. Publ. Univ. California 1868–1918. P. 335-421.

1902. NANSEN, F.: Oceanography of the North Polar Basin. The Norwegian North Polar Exped. 1893–96. Scientific Results, Vol. III, No. 9. 427 pp., pl. 1-33. Christiania 1902.

1915. NANSEN, F.: Spitsbergen Waters. Vid. Selsk. Skrifter. I. Mat-naturv. kl. 1915 No. 2. 132 pp. Christiania 1915.

1923. SCHUMACHER, A.: Neue Hilfstafel usw. Ann. d. Hydr. u. Mar. Met. Vol. LI, 1923. P. 273-280. Berlin 1923.

1931. SUND, OSCAR: Colorimetry at Sea, with a Description of a New Colorimeter. Journal du Conseil, Vol. VI, No. 2. P. 241-245. Copenhagen 1931.

1929. SVERDRUP, H. U.: The Waters on the North Siberian Shelf. The Norwegian North Polar Exped. with the "Maud," 1918–1925, Scientific Results, Vol. IV, No. 2. 131 pp., Tables 75 pp. Bergen 1929.

1931. THOMPSON, T. G. and WIRTH, H. E.: The Specific Gravity of Sea Water at Zero Degrees in Relation to the Chlorinity. Journal du Conseil, Vol. VI, No. 2. P. 232-240. Copenhagen 1931.

ECHO-SOUNDING

ON THE ARCTIC SUBMARINE *NAUTILUS*

BY

FLOYD M. SOULE

III. ECHO-SOUNDING

By FLOYD M. SOULE

CONTRIBUTION NO. 3 FROM THE WOODS HOLE OCEANOGRAPHIC INSTITUTION

The *Nautilus* was provided with a Submarine Signal Company Fathometer equipped for taking shallow soundings up to 125 fathoms by the red-light method and deeper soundings by the white-light method. An impact oscillator was used as a sound source for the red-light method and a small Fessenden type oscillator operating on a 540-cycle alternating-current supply was used for the white-light method. The microphones were located at a distance of 16.8 meters forward of the oscillator in sealed water tanks having the steel skin of the submarine as one side.

Operating conditions were unfavorable and, as was expected, the *Nautilus* proved to be a "noisy" ship. The contributing conditions were as follows: (1) The steel construction of the vessel; (2) the extensive electrical power-system having old wiring and consequently poor insulation; (3) the dripping wet interior conditions caused by condensation of moisture on the cold walls of the submarine; (4) the frequent occurrence of grounds and shorts in spite of the creditable vigilance and diligence of the electrical force; (5) insecure stowage of small stores near the microphone tanks; (6) the scraping of ice against the hull; and (7) occasional noises from the comparatively loose towing pennant.

Noise limited the sounding range to a depth of about 3500 meters. This range might have been greater in quiet water; certainly it was less in the heavy weather encountered away from the ice. Noise and the resulting inability of the observer to distinguish the echo constituted the most important single item interrupting the sounding program. Only one other major interruption occurred. Through some oversight, the port microphone tank had been filled with fresh water when it was installed. As the submarine cooled off, the freezing point was reached and passed, and the microphones were imprisoned in solid ice. Several hours were required to free them without the use of injurious force and to refill the tank with salt water.

Complete calibration of the fathometer before our departure from Bergen was not deemed advisable because of the press of other duties. However, it was desirable to determine which reed of the frequency-meter corresponded most nearly to a velocity of 1450 meters per second and to synchronize on this reed during all soundings. Accordingly, a short series was taken in Bergen on August 3, 1931, in which the time of 190 revolutions of the white light (500 fathoms depth per revolution) was measured with a pocket chronometer.

With the middle reed vibrating at maximum amplitude the mean of three observations of the time of 190 revolutions gave 236.5 seconds, corresponding to a velocity of about 1469 meters per second. With the reed next to the middle on the left vibrating at maximum amplitude the mean of three observations of the time of 190 revolutions gave 239.2 seconds, corresponding to a velocity of about 1453 meters per second.

These measurements were rough but of sufficient accuracy to indicate that the reed next to the middle on the left should be used in all soundings in order to make the work of correction a minimum.

Subsequently in the field (September 5, 1931) a more thorough calibration was made. A Longines stop-watch reading to one-fiftieth second was compared against a Nardin chronometer having a negligible rate, for five periods of four minutes each. The stop-watch readings were 0.50, 0.64, 0.55, 0.56, and 0.66 second, respectively, in excess of four minutes;

TABLE B.—*Sonic Soundings*

SOUNDING No.	LATITUDE NORTH		LONGITUDE EAST		OCEAN. STATION	CORRECTED DEPTH		METHOD	OBSERVER
	°	′	°	′		*meters*	*fathoms*		
45	79	51.2	10	17	*Farm*	290	159	W	FS
46	80	02.5	10	54	"	457	250	W	FS
47	80	07.0	11	14	"	438	239	W	FS
48	80	10.6	11	29	"	328	179	R&W	FS
49	80	15.5	11	48	"	201	110	R	FS
50	80	19.9	12	06	"	194	106	R	FS
51	80	24.3	12	26	"	314	172	R	BV
52	80	27.8	12	41	"	383	209	W	FS
53	80	32.3	12	47	"	787	430	W	BV
54	80	38.1	12	44	"	1248	682	W	FS
55	80	38.9	12	32	"	1378	753	W	HS
56	80	37.2	11	41	"	1023	559	W	RM
57	80	35.3	10	50	"	916	501	W	FS
58	80	32.3	9	28	"	796	435	W	BV
59	80	46.1	10	05	"	1342	734	W	RM
60	80	48.4	10	20	"	1442	788	W	RM
61	80	51.0	10	35	"	1571	859	W	RM
62	80	53.0	10	51	6	1793	980	W	FS
63	80	55.7	11	05	6	1840	1006	W	FS
64	80	58.0	11	20	6	1932	1056	W	HS
65	81	00.5	11	35	6	1914	1047	W	FS
66	81	02.5	11	50	6	1886	1031	W	BV
67	81	04.8	12	07	6	1923	1051	W	HS
68	81	07.0	12	22	6	2053	1123	W	BV
69	81	09.0	12	38	6	2175	1189	W	FS
70	81	11.0	12	55	6	2128	1164	W	BV
71	81	13.2	13	10	6	2202	1204	W	BV
72	81	15.1	13	28	6	2211	1209	W	FS
73	81	17.4	13	44	6	2231	1220	W	BV
74	81	19.2	14	23	1	2183	1194	W	FS
75	81	13.2	11	51	6	2222	1215	W	FS
76	81	11.1	10	46	6	2137	1169	W	FS
77	81	08.0	8	52	7	1118	611	W	FS
78	81	09.0	9	01	7	1211	662	W	FS
79	81	10.8	9	18	7	1229	672	W	FS
80	81	13.0	9	37	7	1238	677	W	FS
81	81	15.0	9	57	6	1275	697	W	HS
82	81	22.8	9	30	7	686	375	W	FS
83	81	26.1	9	47	6	1146	627	W	BV
84	81	30.0	10	06	6	1192	652	W	FS
85	81	33.0	10	23	6	1211	662	W	HS
86	81	36.4	10	36	6	1608	879	W	BV
87	81	40.0	10	52	6	1682	920	W	FS
88	81	43.0	11	05	6	1775	971	W	FS
89	81	46.0	11	12	6	1812	991	W	BV
90	81	49.3	11	13	6	1802	985	W	HS
91	81	53.3	11	15	6	1682	920	W	BV
92	81	53.9	11	38	6	1349	738	W	FS
93	81	54.1	12	00	1	1283	702	W	FS
94	81	54.3	12	24	1	1477	808	W	BV
95	81	54.8	12	49	1	1606	878	W	BV

TABLE B.—*Sonic Soundings—Continued.*

Sounding No.	Latitude North		Longitude East		Ocean. Station	Corrected Depth		Method	Observer
	°	′	°	′		*meters*	*fathoms*		
96	81	55.0	13	15	1	1504	822	W	FS
97	81	55.4	13	44	1	1616	884	W	HS
98	81	56.0	14	09	1	1644	899	W	FS
99	81	56.5	14	40	1	1625	889	W	BV
100	81	54.5	14	20	1	1606	878	W	FS
101	81	53.9	14	06	1	1606	878	W	FS
102	81	52.0	13	39	1	1606	878	W	FS
103	81	52.9	14	21	1	1449	792	W	FS
104	81	53.7	14	44	1	1848	1010	W	RM
105	81	54.5	15	05	1	2080	1137	W	RM
106	81	55.2	15	27	1	2295	1255	W	RM
107	81	56.2	15	49	2 & 3	2178	1191	W	RM
108	81	57.0	16	11	2 & 3	2242	1226	W	RM
109	81	57.9	16	34	2 & 3	2420	1323	W	RM
110	81	58.5	16	55	2 & 3	2597	1420	W	RM
111	81	58.8	17	16	2 & 3	2804	1533	W	RM
112	81	59.0	17	30	2 & 3	2615	1430	W	BV
113	81	49.8	19	47	2 & 3	3465	1895	W	FS
114	81	49.0	19	28	2 & 3	3493	1910	W	RM
115	81	47.1	19	25	2 & 3	3304	1807	W	RM
116	81	45.0	19	18	2 & 3	3237	1770	W	RM
117	81	44.5	19	16	2 & 3	3048	1667	W	S, S
118	81	43.7	19	14	2 & 3	2738	1497	W	FS
119	81	42.3	19	30	2 & 3	1526	834	W	RM
120	81	41.9	19	38	2 & 3	1388	759	W	RM
121	81	37.7	20	45	2 & 3	2307	1261	W	RM
122	81	36.9	21	01	2 & 3	1433	784	W	RM
123	81	34.9	21	30	2 & 3	695	380	W	RM
124	81	34.2	22	04	2 & 3	584	319	W	RM
125	81	34.0	22	17	2 & 3	464	254	W	RM
126	81	33.3	22	55	5	429	235	W	RM
127	81	32.7	23	22	5	161	88	W	RM
128	81	32.2	23	50	5	87	48	W	RM
129	81	31.9	24	04	5	51	28	R	RM
130	81	31.7	24	13	5	134	73	W	RM
131	81	32.2	24	28	5	134	73	W	RM
132	81	35.0	24	36	5	134	73	W	HS
133	81	36.3	24	40	5	318	174	W	HS
134	81	38.0	24	45	5	668	365	W	RM
135	81	37.0	24	45	5	429	235	W	FS
136	..	..	..	..	5	51	28	..	RM
137	81	30.8	24	20	5	141	77	R	M, S
138	81	30.8	24	20	5	141	77	R	M, S
139	81	30.0	24	16	5	143	78	R	M, S
140	81	30.0	24	16	5	141	77	R	M, S
141	81	30.7	23	50	5	235	128	W	RM
142	81	31.7	23	05	5	309	169	W	RM
143	81	31.9	22	46	5	392	214	W	RM
144	81	32.2	22	17	2 & 3	492	269	W	RM
145	81	32.8	21	48	2 & 3	602	329	W	RM
146	81	33.4	21	10	2 & 3	750	410	W	RM

TABLE B.—*Sonic Soundings—Continued*

SOUNDING No.	LATITUDE NORTH		LONGITUDE EAST		OCEAN. STATION	CORRECTED DEPTH		METHOD	OBSERVER
	°	′	°	′		*meters*	*fathoms*		
147	81	34.0	20	43	2 & 3	1388	759	W	RM
148	81	34.4	20	20	2 & 3	1156	632	W	RM
149	81	35.0	19	50	2 & 3	925	506	W	RM
150	81	35.5	19	22	2 & 3	898	491	W	RM
151	81	36.0	18	55	2 & 3	833	455	W	RM
152	81	36.5	18	26	2 & 3	898	491	W	RM
153	81	37.0	17	55	2 & 3	1388	759	W	RM
154	81	39.0	16	20	2 & 3	2457	1343	W	RM
155	81	39.8	15	57	1	2463	1347	W	HS
156	81	40.7	15	44	1	2501	1368	W	BV
157	81	39.6	15	34	1	2501	1368	W	FS
158	81	38.1	15	25	1	2501	1368	W	BV
159	81	36.9	15	14	1	2463	1347	W	BV
160	81	35.8	15	05	1	2426	1327	W	BV
161	81	34.8	14	55	1	2426	1327	W	BV
162	81	33.7	14	46	1	2323	1270	W	FS
163	81	32.5	14	36	1	2295	1255	W	FS
164	81	31.3	14	26	1	2210	1208	W	FS
165	81	29.8	14	16	1	2192	1199	W	FS
166	81	28.2	14	06	1	2183	1194	W	BV
167	81	26.9	13	56	1	2201	1204	W	BV
168	81	25.8	13	47	6	2175	1189	W	BV
169	81	24.6	13	37	6	2155	1178	W	FS
170	81	23.2	13	27	6	2155	1178	W	FS
171	81	21.8	13	17	6	2155	1178	W	BV
172	81	20.7	13	06	6	2155	1178	W	BV
173	81	22.0	12	59	6	2166	1184	W	FS
174	81	23.7	12	52	6	2146	1173	W	HS
175	81	25.3	12	46	6	2137	1169	W	HS
176	81	26.8	12	40	6	2166	1184	W	BV
177	81	28.2	12	32	6	1849	1011	W	FS
178	81	30.0	12	25	6	1460	798	W	FS
179	81	31.7	12	17	6	1589	869	W	HS
180	81	33.0	12	10	6	1905	1042	W	BV
181	81	34.4	12	03	6	1942	1062	W	FS
182	81	36.0	11	55	6	1960	1072	W	FS
183	81	37.3	11	48	6	1942	1062	W	FS
184	81	38.9	11	41	6	1914	1047	W	FS
185	81	40.4	11	35	6	1886	1031	W	FS
186	81	41.8	11	28	6	1867	1021	W	BV
187	81	44.0	11	16	6	1775	971	W	BV
188	81	39.5	11	21	6	1599	874	W	BV
189	81	38.2	11	20	6	1793	980	W	BV
190	81	36.6	11	18	6	1783	975	W	BV
191	81	36.2	11	06	6	1664	910	W	BV
192	81	35.2	11	01	6	1617	884	W	BV
193	81	33.1	11	00	6	1561	854	W	BV
194	81	31.1	10	50	6	1385	757	W	BV
195	81	29.6	10	40	6	1293	707	W	BV
196	81	28.5	10	28	6	1118	611	W	FS
197	81	27.5	10	15	6	1118	611	W	FS

TABLE B.—*Sonic Soundings—Continued*

SOUNDING No.	LATITUDE NORTH		LONGITUDE EAST		OCEAN. STATION	CORRECTED DEPTH		METHOD	OBSERVER
	°	′	°	′		*meters*	*fathoms*		
198	81	26.5	10	02	6	1109	606	W	BV
199	81	25.6	9	49	6	1026	561	W	BV
200	81	24.7	9	35	6	970	530	W	BV
201	81	23.8	9	22	7	833	455	W	BV
202	81	23.8	9	06	7	658	360	W	BV
203	81	24.0	8	52	7	602	329	W	BV
204	81	24.4	8	37	7	556	304	W	RM
205	81	24.9	8	23	7	464	254	W	RM
206	81	25.3	8	09	7	455	249	W	HS
207	81	25.8	7	54	7	400	219	W	BV
208	81	26.1	7	40	7	824	451	W	RM
209	81	24.5	7	05	7	815	446	W	RM
210	81	24.5	7	05	7	842	460	W	RM
211	81	23.8	6	58	7	787	430	W	BV
212	81	23.0	6	50	7	797	436	W	BV
213	81	23.0	6	35	7	758	414	W	BV
214	81	22.7	6	23	7	630	344	W	FS
215	81	20.8	6	17	7	667	365	W	BV
216	81	19.1	6	10	7	676	370	W	HS
217	81	17.4	6	01	7	722	395	W	FS
218	81	16.0	5	50	7	731	400	W	FS
219	81	14.6	5	39	7	704	385	W	FS
220	81	14.1	5	26	7	686	375	W	HS
221	81	14.2	5	13	8	658	360	W	FS
222	81	13.1	5	05	8	667	365	W	FS
223	81	12.5	5	03	8	686	375	W	FS
224	81	09.0	4	58	8	667	365	W	FS
225	81	06.9	4	54	8	695	380	W	FS
226	81	04.8	4	50	8	695	380	W	FS
227	81	03.4	4	47	8	686	375	W	FS
228	81	00.5	4	41	8	704	385	W	FS
229	81	00.8	4	30	8	695	380	W	FS
230	81	01.0	4	20	8	704	385	W	FS
231	81	00.4	4	10	8	750	410	W	BV
232	80	59.0	4	00	8	759	415	W	HS
233	80	57.4	3	51	8	795	435	W	BV
234	80	57.1	3	37	8	924	505	W	RM
235	80	57.0	3	25	8	924	505	W	RM
236	80	56.9	3	10	8	999	546	W	RM
237	80	54.8	3	07	8	1017	556	W	BV
238	80	52.3	3	04	8	1063	581	W	RM
239	80	50.4	3	02	8	1109	606	W	RM
240	80	48.1	2	58	8	1146	627	W	RM
241	80	46.0	2	55	8	1247	682	W	RM
242	80	44.0	2	52	8	1266	692	W	RM
243	80	42.2	2	44	*Farm*	1351	739	W	RM
244	80	40.8	2	34	"	1609	880	W	BV
245	80	39.4	2	23	"	1804	986	W	BV
246	80	37.8	2	14	"	1906	1042	W	BV
247	80	36.0	2	04	"	2175	1189	W	BV
248	80	34.3	1	53	"	2372	1297	W	BV

TABLE B.—*Sonic Soundings—Continued*

SOUNDING No.	LATITUDE NORTH		LONGITUDE EAST		OCEAN. STATION	CORRECTED DEPTH		METHOD	OBSERVER
	°	′	°	′		*meters*	*fathoms*		
249	80	33.0	1	42	*Farm*	2596	1419	W	BV
250	80	31.4	1	32	"	2691	1471	W	RM
251	80	30.9	1	18	"	3161	1728	W	M, S, V
252	80	30.9	1	11	"	3133	1713	W	RM
253	80	30.9	1	11	"	3161	1728	W	RM
254	80	30.9	1	05	"	3170	1733	W	BV
255	80	30.9	0	55	"	2889	1580	W	BV
256	80	30.9	0	41	"	2504	1369	W	BV
257	80	30.9	0	30	"	2335	1277	W	BV
258	80	29.1	0	20	"	2335	1277	W	BV
259	80	27.5	0	10	"	2316	1266	W	BV
260	80	26.0	0	00	"	2513	1374	W	RM
261	80	24.8	359	51	"	2747	1502	W	RM
262	80	23.1	359	42	"	2399	1312	W	FS
263	80	21.8	359	34	"	2298	1257	W	BV
264	80	20.1	359	24	"	2102	1149	W	FS
265	80	18.8	359	15	"	2689	1470	W	BV
266	80	17.2	359	05	"	2747	1502	W	HS
267	80	15.2	358	59	"	2747	1502	W	BV
268	80	13.0	358	55	"	2756	1507	W	RM
269	80	11.0	358	50	"	2784	1522	W	BV
270	80	09.4	359	03	"	2710	1482	W	FS
271	80	08.5	359	18	"	2654	1451	W	FS
272	80	08.1	359	25	"	2689	1470	W	BV
273	80	07.8	359	37	"	2645	1446	W	FS
274	80	07.0	359	49	"	2663	1456	W	FS
275	80	06.4	0	00	"	2729	1492	W	HS
276	80	06.0	0	11	"	2673	1462	W	FS
277	80	05.3	0	23	"	2689	1470	W	HS
278	80	04.8	0	34	"	2689	1470	W	BV
279	80	04.2	0	45	"	2737	1497	W	RM
280	80	03.9	0	55	"	2307	1261	W	RM
281	80	03.2	1	06	"	2596	1419	W	RM
282	79	52.7	4	38	"	1110	607	W	RM
283	79	48.2	6	10	"	1850	1012	W	RM
284	79	44.6	7	20	"	1295	708	W	RM
285	79	42.8	7	56	"	1000	547	W	FS
286	79	36.3	8	06	"	834	456	W	FS
287	79	30.1	8	17	"	760	416	W	FS
288	79	26.5	8	22	"	623	341	W	FS
289	79	23.5	8	30	"	429	235	W	FS
290	79	22.9	8	36	"	337	184	W	FS
291	79	22.4	8	39	"	309	169	W	FS
292	79	22.0	8	42	"	300	164	W	FS
293	79	21.5	8	45	"	281	154	W	FS
294	79	21.1	8	48	"	272	149	W	FS
295	79	20.6	8	52	"	263	144	W	FS
296	79	20.1	8	56	"	254	139	W	FS
297	79	19.5	9	00	"	254	139	R	FS
298	79	18.6	9	07	"	236	129	R	RM
299	79	18.0	9	12	"	208	114	R	RM
300	79	17.5	9	15	"	197	108	R	RM

From the soundings listed in Table B combined with all available prior soundings in the vicinity in question, the bathymetric chart shown in fig. 45 has been constructed. Contour lines representing the 200, 500, 1000, 1500, 2000, 2500, 3000, and 3500 meter-levels are shown as unbroken lines, although it is realized that they are, in part, conjectural. Aside from the *Nautilus* data, the following soundings were used in addition to others appearing on British Admiralty Chart No. 2751, Norwegian Chart No. 303, and Mohn's bathymetric chart of the Norwegian Sea[2].

---

[2] H. Mohn, The North Ocean, its Depths, Temperature, and Circulation. The Norwegian North-Atlantic Expedition 1876–78, Vol. 2 [Part 18] Pl. 1, Christiania, 1887.

TABLE C.—*Soundings Obtained by Previous Expeditions*

SOUNDING BY	LAT. NORTH	LONG. EAST	DEPTH	SOUNDING BY	LAT. NORTH	LONG. EAST	DEPTH
	° ′	° ′	m		° ′	° ′	m
Ringsael—1922	80 25	16 30	382	*Sofia*[3] . . .	80 47	2 20	1298
(unpublished)	80 40	16 30	748		81 00	3 55	786
	81 00	16 30	2130		80 29	3 05	1152
	81 13	17 15	1806		79 52	4 45	1737
	81 29	17 15	3076		80 44	8 50	1335
					80 34	11 10	558
Belgica[1] . . .	79 52	10 42	310		80 45	10 55	713
	80 04	10 05	650		80 38	12 10	923
	80 05.5	9 40	550[a]		81 09	11 35	1700
	80 13.5	7 42	560		80 52	14 55	1382
	80 17.5	5 40	735		81 04	16 10	677
	80 03	2 47	1800[a]		81 07	15 35	713
	79 34	2 40	1800[a]		81 21	17 00	2450
	79 56	1 29	2275		81 42	17 15	2505
	79 12	1 52	3400				
	78 43	0 00	2520	*Quest*[4] . . .	80 11	16 50	227
					80 19	16 20	187
Jermak[2] . . .	80 05	8 40	450		80 28	15 50	109
	80 45	9 16	938		80 37	15 10	102
	80 35	7 19	724		80 40	14 55	148
	80 39	4 57	700		80 41	13 55	732
	81 14	18 30	497		80 39	13 30	799
	81 27	18 10	722		80 34	13 20	314
	80 57	20 05	195		80 34	13 20	311
	81 01	19 28	180		80 30	13 10	155
	79 49	9 45	444		80 24	13 05	183
	79 41	4 58	2857		80 19	12 55	187
					80 14	12 50	200

TABLE REFERENCES

[a] Depths greater than those entered.

[1] Duc d'Orléans, Croisière océanographique dans la mer du Grönland, en 1905, Resultats scientifiques, Bruxelles (1907).

[2] S. Makarof, Jermak in the Ice (in Russian), St. Petersburg (1901).

[3] Svenska Polar-Expeditionen år 1868 (in Swedish), Stockholm (1869). [Soundings entered on map.]

[4] Unpublished results supplied through the courtesy of Prof. Ahlmann.

As to the positions of the soundings of the *Ringsael*, it should be remarked that the positions of the two northern soundings were given originally as 81° 13′ N., 17° 55′ E.

and 81° 29′ N., 19° 22′ E. As these positions would indicate a most irregular bottom, they have been changed to the tabulated values, since Dr. Devik, who had charge of the *Ringsael* expedition, admitted that the longitude at the northern stations might be considerably in error and perhaps more westerly than originally assumed, because of easterly winds and lack of observations. Although it seems probable that the longitude of the sounding at 81° 00′ N., 16° 30′ E. is also too far east, it has been retained as there is other substantiation for the existence of this depression.

The most salient feature brought out by the soundings of the *Nautilus* is the general configuration of the Spitsbergen-Greenland ridge. It seems that the main ridge extends from the Greenland peninsula of Northeast Foreland in a direction about N. 60° E. into the Polar Sea north of West Spitsbergen, while a second ridge whose axis is nearly perpendicular to the first connects it with the northwestern part of Spitsbergen, thus completing the threshold between the Polar and Greenland seas. A valley communicating with the depths of the Polar Sea is thus formed north of West Spitsbergen between it and the extension of the first-mentioned ridge. The continental shelf extending northward from Northeast Land for 70 or 80 miles rapidly drops to oceanic depths near the mouth of this valley. The soundings of the *Nautilus* are not extended far enough to the northwest to give definite information as to the saddle depth of the Spitsbergen-Greenland ridge. When Nansen first conjectured the existence of this ridge, which now ought to bear his name, he supposed the saddle depth to be 700 or 800 meters, but later on he arrived at the result that the saddle depth probably was deeper and lying between 1100 and 1500 meters. The oceanographic observations on the *Nautilus*, which have been discussed above by Dr. H. U. Sverdrup (p. 42), support the latter opinion; and if it is correct, the saddle depth lies to the west of the region which has been explored. The soundings reveal another depression below 3000 meters at about 80° 20′ N. and 1° E. This is probably the most northerly of the series of depressions which characterize the Norwegian and Greenland seas.

Figure 46 shows a vertical section along the route of the *Nautilus* from 80° 11′.0 N. and 1° 10′ W. along the northwestern side of the above-mentioned depression, across the second-mentioned ridge to a point near the head of the northern valley at 81° 41′.8 N. and 11° 28′ E. The figure does not represent a great-circle section, but a somewhat irregular path including soundings 269 to 229, 227 to 188, and 186.

While these contributions shed additional light on the circulation in the Greenland Sea, it is to be hoped that the near future will bring the further development of the Spitsbergen-Greenland ridge and its extension into the Polar Sea.

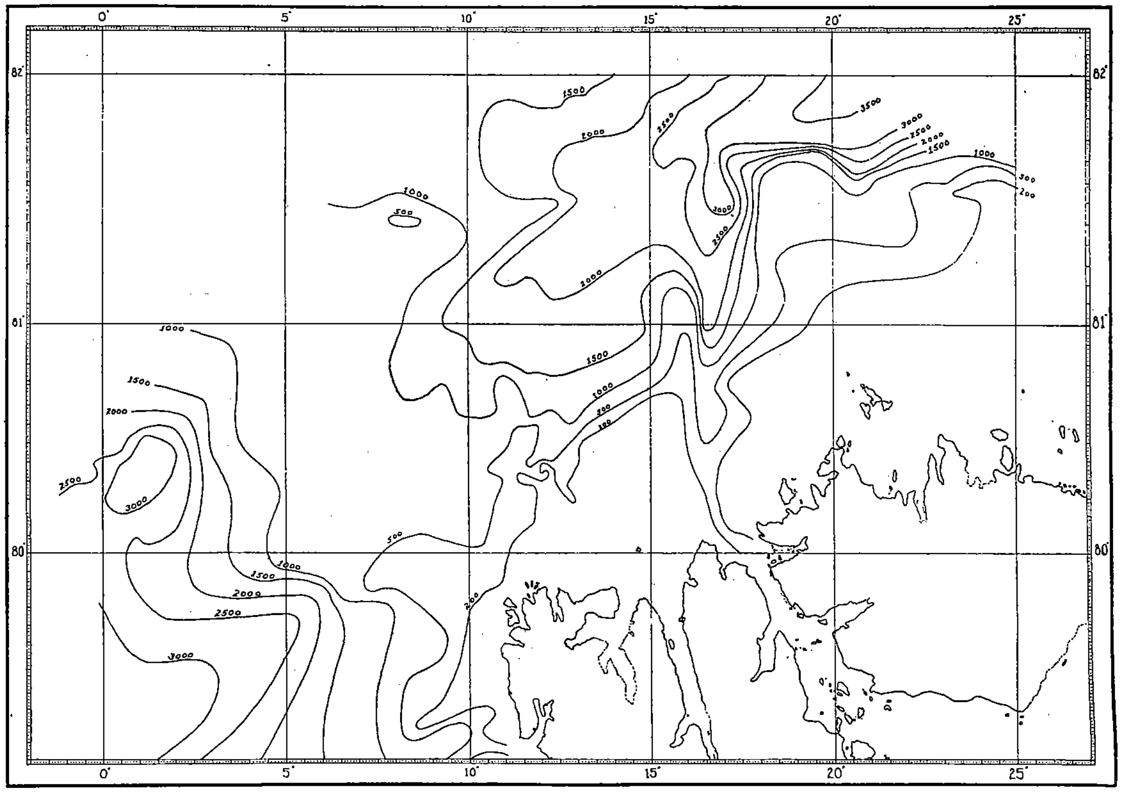

FIG. 45.—Bathymetric chart of the area explored by the *Nautilus* and neighboring areas to the north of Spitsbergen. Depths in meters

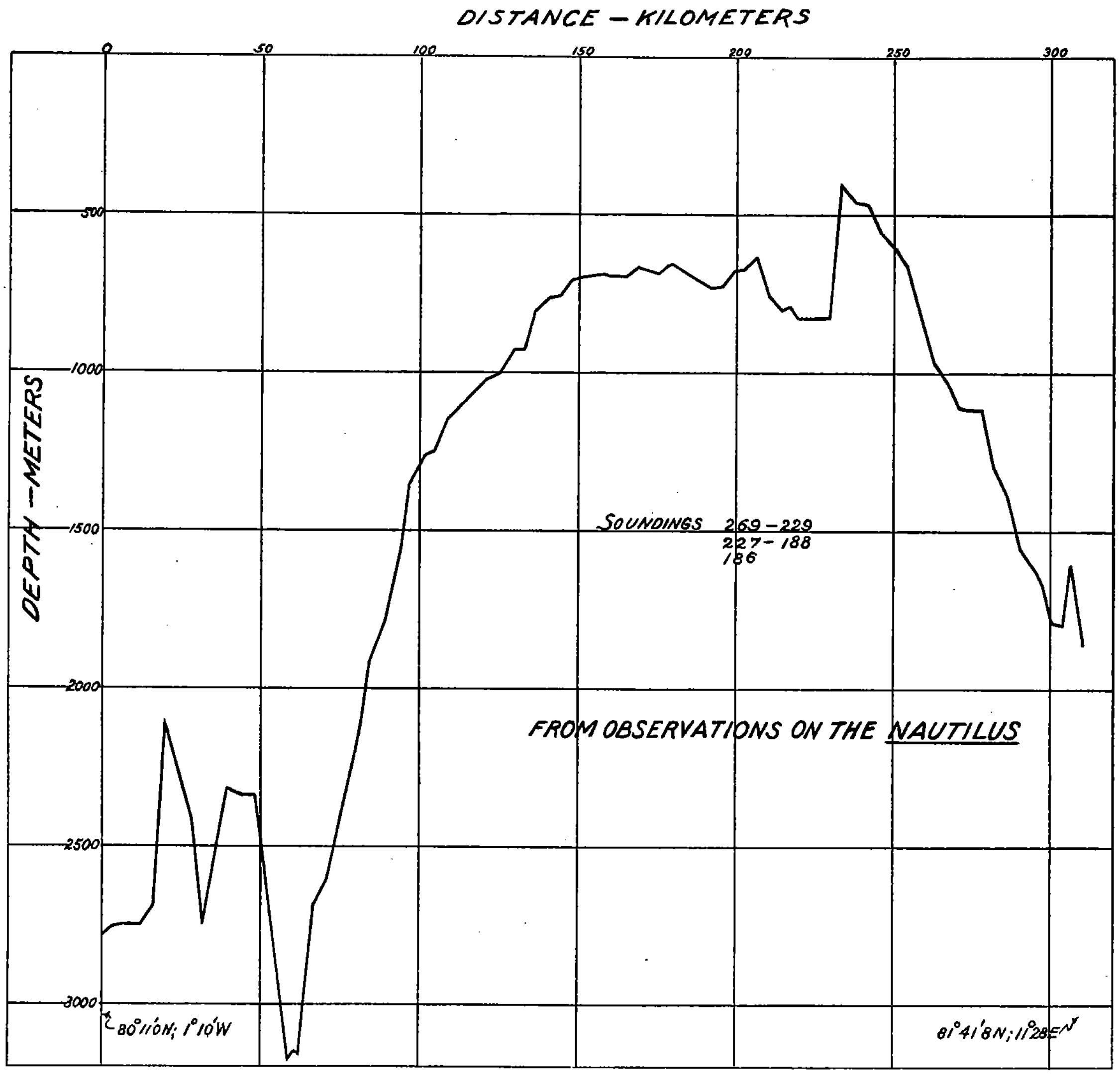

FIG. 46.—Vertical section along the route of the *Nautilus* (see page 74)