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SCIENTIFIC RESULTS OF THE "NAUTILUS" EXPEDITION, 1931

Under the Command of Capt. Sir Hubert Wilkins

PARTS I TO III

BY

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AND

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CAMBRIDGE, MASSACHUSETTS

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

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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,

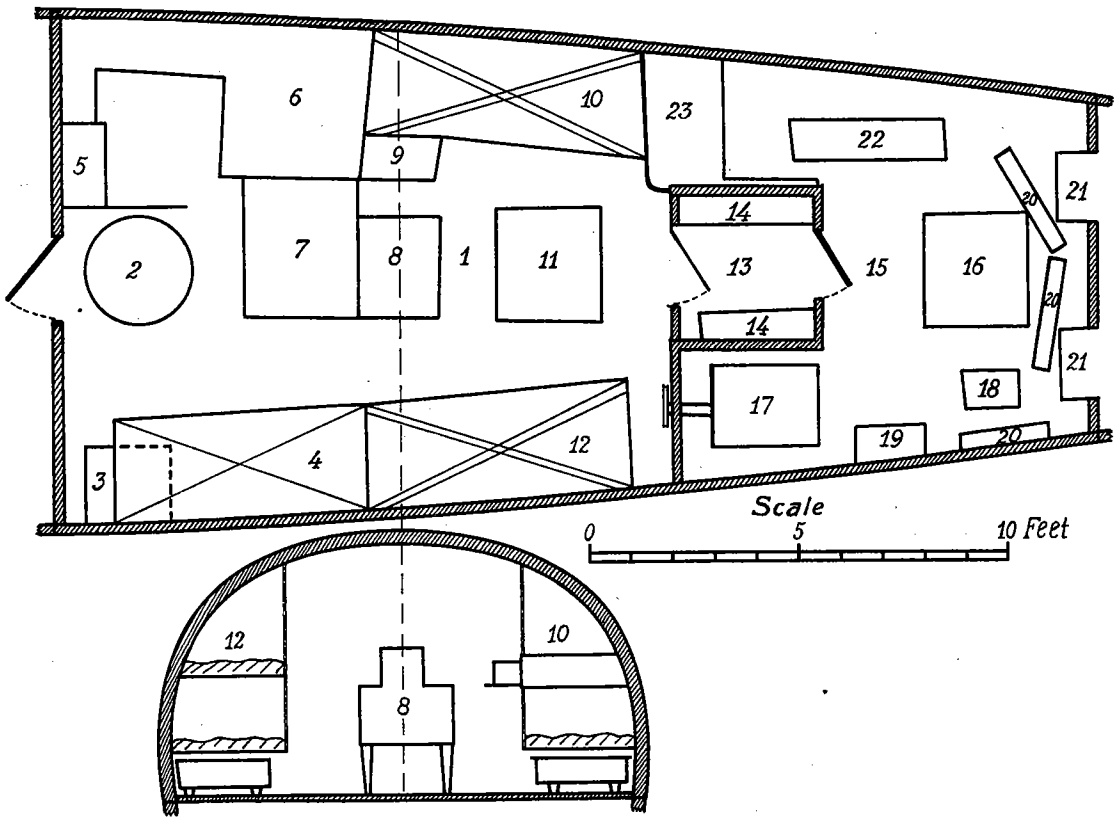

FIG. 1.—Plan of the compartment for the scientists, and of the diving compartment

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.

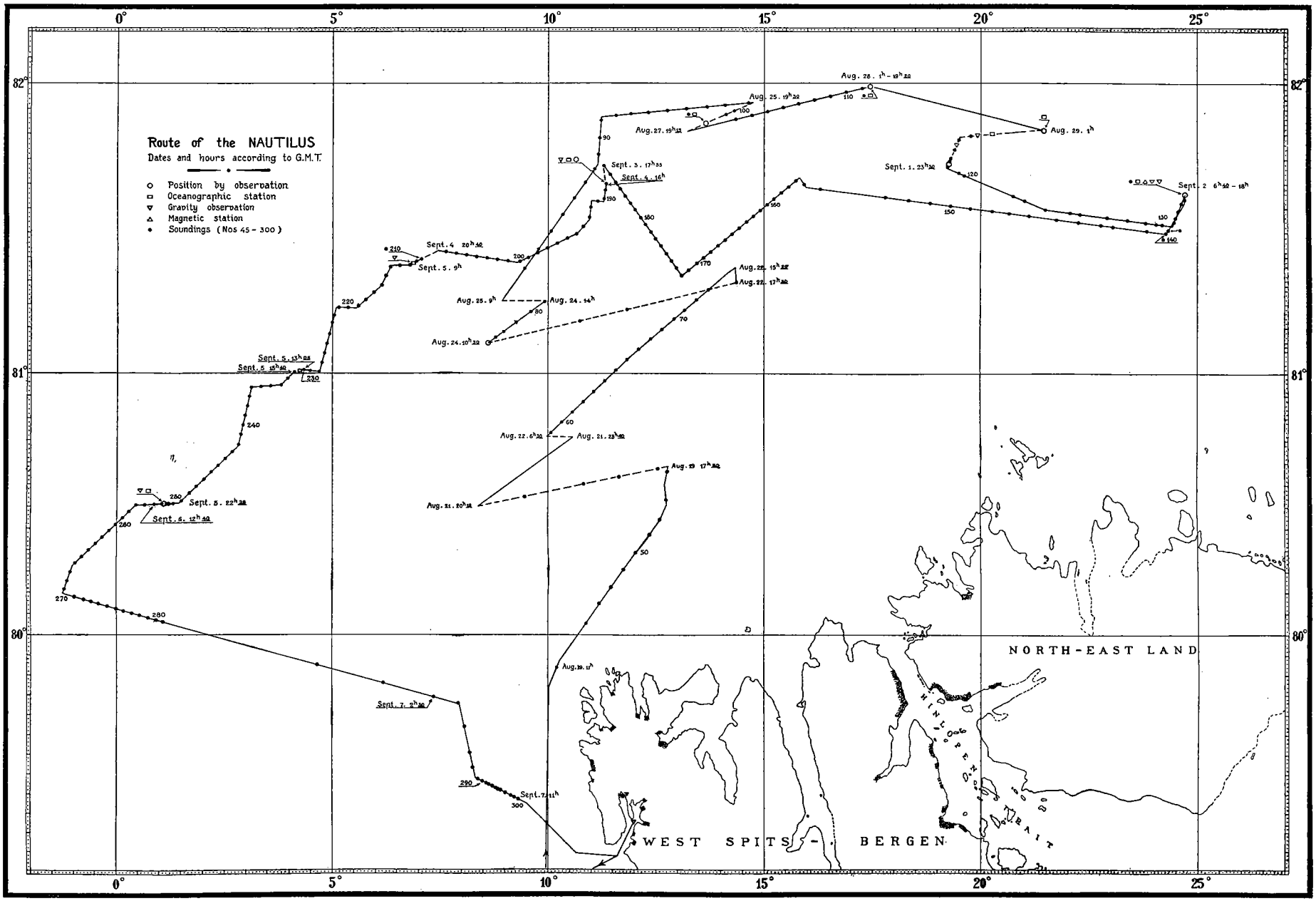

FIG. 2.—Chart of the route of the *Nautilus*

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 sound-

ings. 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

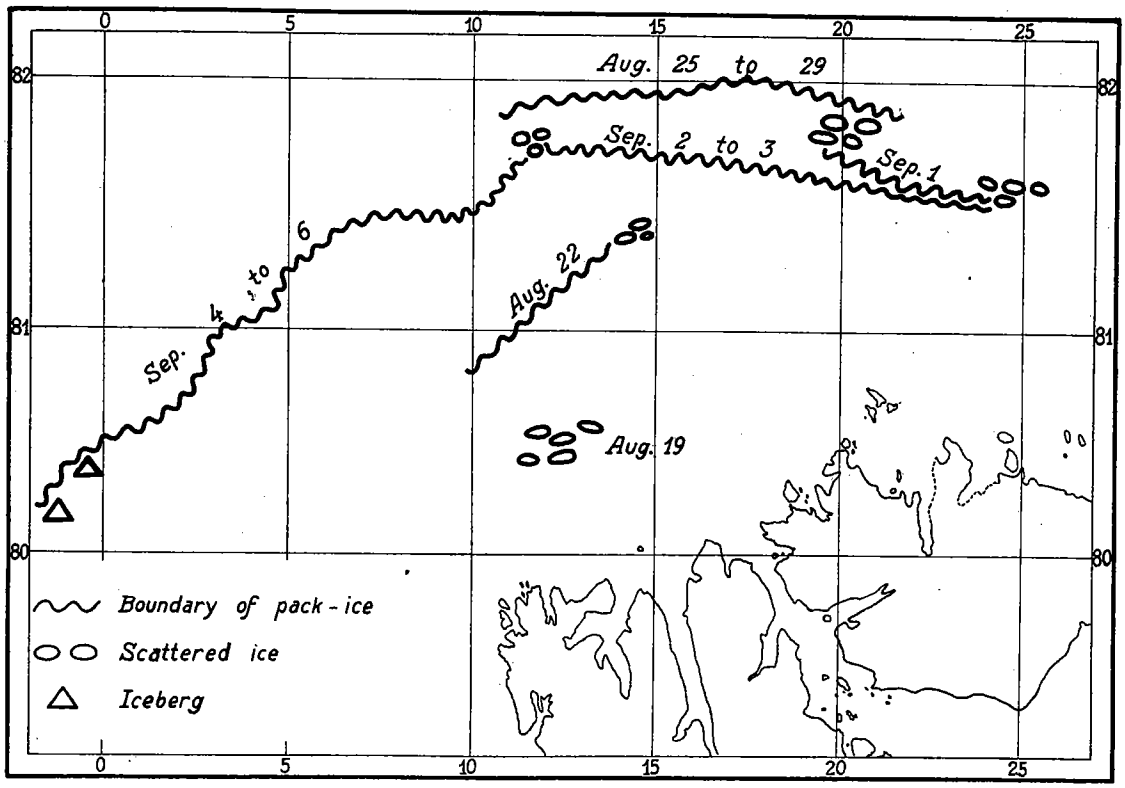

Fig. 3.—The ice to the north of Spitsbergen between August 19 and September 6, 1931

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.

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