3 1761 C
D
15

GC
491
N36

*H. L. Mecking
mit freundlichen Grüßen
vom Verf.*

THE WATERS OF THE NORTH-EASTERN NORTH ATLANTIC

INVESTIGATIONS MADE DURING
THE CRUISE OF THE FRITHJOF, OF
THE NORWEGIAN ROYAL NAVY,
IN JULY 1910

BY

FRIDTJOF NANSEN

111

WITH 52 TEXT-FIGURES AND 17 PLATES

567366
30.7.53

LEIPZIG 1913

PUBLISHED BY DR. WERNER KLINKHARDT

GC
491
N 36

701.00

CONTENTS.

	Page
<i>Preface</i>	1
I. <i>Introduction</i>	2
II. <i>The Route of the Frithjof and the Sections</i>	5
III. <i>Instruments and Methods</i>	6
Sounding Machine and Winch (6). Water-Bottles (7). Thermometers and Temperatures (8). Water-Samples and Salinities (14).	
IV. <i>The deep Vertical Circulation of the Top Layers of the North-eastern North-Atlantic</i>	15
Variations in Salinity due to Vertical Circulation (16). The so-called Vertical Convection Currents (18). The Effect of the Deep Vertical Circulation upon the Climate (20). The Penetration of the Heat from the Sun towards the Depth (21). Seasonal Variation of the Surface-Salinity owing to Precipitation and Vertical Circulation (22). Water over Banks in the Ocean (24).	
V. <i>The Rockall Channel and the Irish Current</i>	27
The Vertical and Horizontal Distribution of Temperature, Salinity, and Density in Section I, across the Rockall Channel (41). The Horizontal Motion of the Water (44). On the Calculation of the Velocities of Ocean Currents (46).	
VI. <i>The Deep-Water of the Rockall Channell, partly from the Mediterranean Sea</i>	56
VII. <i>The Origin of the Irish Current, the so-called "Gulf Stream", through the Rockall Channel</i>	67
VIII. <i>Variations in the Temperature of the Irish Current in different Years</i> .	88
IX. <i>The North Atlantic between the Rockall Bank and Iceland</i>	95
X. <i>Annual Variations in the Temperature of the Sea south and west of Iceland, and the Winter Temperature of south-western Iceland</i>	99
XI. <i>The East Icelandic Arctic Current</i>	106
XII. <i>The Waters of the Faeroe-Shetland Channel</i>	109
XIII. <i>The supposed Bank north-east of the Faeroes</i>	119
Table, giving the Observations taken on board the Frithjof, July 6 th —21 st , 1910	121
Literature	135
Explanation of the Plates	139

Preface.

This paper describes the results of oceanographic investigations in the north-eastern Atlantic made in July 1910, during a cruise with the Norwegian gun-vessel Frithjof.

I wish here first of all to express my deep gratitude to His Majesty the King of Norway, to the Norwegian Government, and to the authorities of the Norwegian Navy for their most valuable assistance in sending the ship, at my request, into the North-Atlantic, and by giving me every facility for making observations on board during the cruise. I hope the following pages will prove that results of sufficient value to justify their obligingness, have been attained.

It is also my pleasant duty to offer my sincere thanks to Captain Caspar S. Erlandsen, the Commanding Officer of the Frithjof, for the great interest he took in my work from the very beginning, and for the valuable assistance and many facilities he gave me in every respect.

I wish to thank the other officers on board, especially Commander Gabriel Mörch and the navigating Officer Commander J. Smith-Johannsen, for their never-failing readiness to help and for their great kindness.

To the many men of the crew who were constantly working at my winches, and to the electricians who looked after the electric motor, I owe my warmest gratitude. I will further specially mention the two Boatswain's Mates, Adolf Martinius Johansen and Nikolai Adolf Nilsen, who worked hard as my trustworthy assistants during the cruise. They always helped me in my work day and night, and also

took regular observations of the strata between the surface and 200 metres, while I was below.

I am very grateful to the Cadets on board, who took the observations of the sea-surface during the whole cruise.

Special thanks are due to the electric firm Norsk Elektrisk & Brown Boveri of Christiania for lending me an electric motor for the soundings.

Finally I wish to take this opportunity of thanking my friend Dr. Björn Helland-Hansen for his great help in arranging and superintending the titrations of the water-samples and I also thank Mr. Illit Gröndahl B. A. who made most of the titrations of the samples.

I. Introduction.

During recent years, especially since 1900, the Oceanography of the Norwegian Sea has been well studied, chiefly by the Norwegian Marine and Fishery-Investigations organized and led by Dr. Johan Hjort. Thus the physical conditions of this sea-basin have become far better known than those of any other area of the deep Ocean; it is in fact the only part of the Ocean in which the physical conditions are to some extent known in detail.

The study by Dr. Björn Helland-Hansen and myself [1909] of the physical observations collected during the Norwegian researches, brought to light what an important influence variations in the Norwegian Atlantic Current have upon the physical conditions (of the sea as well as of the atmosphere) of this sea-area and neighbouring regions, especially Norway. It appeared that variations in the temperature of the Atlantic Current from one year to another, were followed by corresponding variations in the winter-climate of Norway, and also by variations in the fisheries of the North Sea and at Lofoten, etc. We found a remarkable similarity between the annual variations in the surface-temperatures of the current in May and the variations in the harvests of Norway, the growth of the pine forests, etc. We also pointed out the possibility of a relation of some kind between the annual variations of this current and cosmic causes (variations of the sun-spots).

Several later investigations seem in various respects to confirm the correctness of our conclusions.

Owing to the inadequacy of the material of observations at our disposal, from other regions of the Sea, we were not able to decide

whether the observed annual variations in the volume and temperature of the Norwegian Atlantic Current were due to variations in the physical conditions of the North Atlantic, south of the Wyville Thomson Ridge and the Faeroe-Iceland Ridge, or of other causes, *e. g.* variations in the East-Icelandic Arctic Current.

In order to approach the solution of this important problem, it is naturally necessary to study the physical conditions and the circulation of the North Atlantic, and it would be of special interest to know the conditions of the so-called "Gulf-Stream", west of the British Isles, supposed to form the Norwegian Atlantic Current running towards the northeast, chiefly through the Faeroe-Shetland Channel.

Considering the important interest connected with the northern areas of the North Atlantic, between Ireland, Iceland, Greenland, Newfoundland, and the American coast, it is, indeed, remarkable how very little the physical conditions of this region have been studied by modern scientific methods. The consequence being a deplorable lack of knowledge, which is, as yet, an impassable hindrance to our being able to solve the above mentioned problems of the circulation of the Norwegian Sea.

Having been continually hampered in our oceanographic studies by our ignorance of the above mentioned region, and feeling keenly the necessity of more knowledge in this respect, I have, for years, been planning an investigation, on a modest scale, of the physical conditions of the north-eastern North-Atlantic. My object was first of all to trace out the great leading features in the circulation of the sea in this region. Various circumstances hindered me from carrying out my plan. In 1909, however, I fitted out my little yacht "Veslemøy" for the purpose. The Nansen Fund gave a grant of Kr. 5000,00 towards the expences of the equipment. Otherwise the cost of this cruise as well as the cruise and investigations of subsequent years has been borne by myself.

Owing to several unexpected difficulties I was not able to start till two months later in the summer than intended, and there was not sufficient time left that season for such a long cruise. I had therefore to turn to investigations nearer home.

Being busy with other work in 1910, I could not afford the time for a long cruise that summer, but in order to be enabled to do something of importance in the way of a preliminary research, I asked the Norwegian Government whether a ship of the Norwegian Royal Navy could possibly be sent on her summer-cruise into those waters, and

there could be given me an opportunity of taking oceanographic observations at a number of stations during the voyage; I would procure all instrumental outfit and gear, and would defray all extra expenses connected with these observations. Our War and Navy Department and the naval authorities met my request with great kindness. It was arranged that the gun-vessel "Frithjof", the training ship of the Cadets, should take me on board in Belfast in the beginning of July 1910. From Ireland we should follow a straight course across the southern part of the Rockall Bank towards a point in about 61° N. Lat. and 37° W. Long. (off the east coast of Greenland), then to Seydis Fjord on the east coast of Iceland for taking coal, and thence back to Norway passing north of the Faeroes.

My plan in proposing this route was first of all to study the region of the so-called "Gulf Stream" west of Ireland and the Rockall Bank by a number of Stations with comparatively short intervals. Secondly to study the physical conditions in the area east of southern Greenland where I suppose that an important part of the bottom-water of the North Atlantic is being formed by emission of heat from the surface during the Winter.¹⁾

The latter part of my investigations had, however, to be given up, owing to the fact that the coal which the "Frithjof" had obtained was less durable than expected. In order not to risk running short of coal Captain Erlandsen therefore wisely decided to shape our course for the east coast of Iceland earlier than originally intended. In this manner I got an oceanographic section northward towards the submerged shelf of eastern Iceland which proved to be of much interest.

On our way home from Iceland I intended to study the East-Icelandic Arctic Current, by stations at short intervals; and I also hoped to get an opportunity of ascertaining by soundings whether the supposed bank to the north-east of the Faeroes, indicated by a sounding of 204 fathoms (373 metres) of the "Vöringen" in 1876, really exists. Finally I wished to take a section with a great number of stations across the Faeroe-Shetland Channel.

With the one exception of the region south west of Iceland and east of Greenland, the program was successfully carried out, in a very short time, thanks to the excellent manner in which the cruise was conducted by Captain Erlandsen, and to the kind and always ready help of the officers and crew of the "Frithjof", both day and night.

¹⁾ Cf. Nansen, 1912.

II. The Route of the Frithjof and the Sections.

The route of the Frithjof, with the oceanographic stations, is shown in Fig. 1, and also in the charts Pls. I—VIII.

We left Belfast on July 6th, 1910, and reached Seydis Fjord, Iceland, on July 13th. On July 16th, we went to Mjö Fjord just south

Fig. 1. Sections I—V of the Frithjof, July 1910; the Sections (A and B) of the Fram, June and July 1910; Scottish Sections C, D, M, and N of August 1910; Danish Sections E and F of May and June 1905, and H and K of May 1908; Section P of the Porcupine, June 1869.

of Seydis Fjord, and on the afternoon of the same day we put to sea on our homeward voyage. On July 21st we reached Bergen.

The observations of Temperature and Salinity, collected during the cruise, are given in the Table appended to this paper, with dates, hours, and depths.

On the basis of these observations, five sections have been drawn.

Section I (Pls. IX—XI) runs along the first part of the route from the shallow sea just north of Ireland, where we were on July 6th, 1910, across the Rockall Channel and Rockall Bank to Station 12, where we were on the evening of July 9th, 1912.

Section II (Pl. XII—XIII) runs from Station 12 to Station 21, on the submerged shelf off the east coast of Iceland, where we were on July 12th, 1910. From this station we went in to Seydis Fjord, where we stayed for three days.

Section III (Pls. XIV—XV) runs from the mouth of the Mjö Fjord (July 16th) to Station 35 (July 18th) north-east of the Faeroes.

Section IV (Pls. XVI—XVII) runs from Station 35 to Station 39 (July 19th), on the Faeroe Platform.

Section V (Pls. XVI—XVII) runs from Station 39 across the Faeroe-Shetland Channel to Station 48 (July 20th) north of Shetland.

III. Instruments and Methods.

Sounding Machine and Winch.

The sounding machine belonging to the Frithjof, with a steel-wire of 2 mm diameter, was used for the automatic water-bottle. The machine was placed on the deck aft, and the line ran out over a meter-wheel at the stern of the ship.

A steel-wire of 3 mm diameter was used for all deep-sea observations not taken with the automatic water-bottle. I had constructed a special winch for the hauling up of the line. It was made by the "Tenfjords mekaniske Verksted" (Aalesund). The winch was very handy to manipulate. By a special arrangement it could also be used for automatic sounding, even with the wire of 3 mm. For hauling in, the winch was connected with an electric motor, kindly lent me as already mentioned, by the electric engineering firm Norsk Elektrisk & Brown Boveri, Christiania.

When the motor went at full speed, 150 or even 200 metres of line could be hauled up in one minute. From this winch, the line was rolled on to a drum by hand.

As the electric current at our disposal onboard was not quite suitable for the electric motor, the latter could not develop its full power. The consequence was that whenever more than 1200 or 1500 metres of 3 mm wire were let out, the motor was not strong enough to haul it up again. For fear something might break, I had

therefore to give up the hope of taking observations from depths greater than 200 metres, and even this depth I only ventured to risk attempting a few times.

Water-Bottles.

A new automatic, insulating water-bottle of my own construction was used for depths between the surface and 400 to 500 metres.

By comparisons with the temperature readings of the Richter reversing thermometers, it was proved that this instrument gave a quite satisfactory insulation of the temperature down to 400 or 500, or even 600 metres.

With this water-bottle we could easily take observations down to 200 or 300 metres, while the ship was going at a speed of between seven and eight knots which, being most economical as to coal, was our ordinary speed during the cruise. In order to reach a depth of 300 metres we had then to let out about 600 metres of line. As we had not more line on the winch we could not reach deeper while the ship was going at a speed above seven knots.

The bottle was hauled up by hand. The depth was measured, at the moment the bottle was closed, by a double depth-meter based on the principle of the compression of air.

For taking observations at depths greater than 200 or 300 metres we had to stop. Owing to its handiness, the automatic water-bottle was then generally used, down to 400 or 500 metres. Beyond this limit, the temperatures were taken with the Richter reversing thermometers.

Two stop-cock water-bottles of my construction, with arrangement for reversing thermometers, were attached to the side of the line at different depths during most deeper soundings. They always worked well, closed tightly, and gave perfectly trustworthy water-samples.

A new reversing stop-cock water-bottle of my construction was much used, on the side of the line or at the end. In order to protect the reversing thermometer against too much heating while being hauled up through warmer water-strata, it is here placed inside the water-bottle, which is to some extent insulated by a casing of ebonite. This precaution seems, however, to be unnecessary with the Richter reversing thermometer, even in the Tropics, as its readings cannot easily be spoilt by additional mercury being shaken down after the reversing of the instrument. For less perfect thermometers, the arrangement may be useful. The water-bottle has a simple construction, and is handy to work.

By using simultaneously the above mentioned three water-bottles, attached to the line at certain intervals, it was possible to complete a series of deep-sea observations down to 1500 or 2000 metres in a couple of hours.

A Pettersson-Nansen water-bottle was used at some of the first stations, but the spiral-spring working the arrangement for the reversing thermometer, then got out of order and could not be repaired on board.

Thermometers and Temperatures.

All thermometers used during the cruise were some years old. I tested their freezing-points before we started. They showed no appreciable alterations from the corrections found in previous year. All readings of the thermometers during the cruise (except those of the sea surface) were taken with the reading lens of my construction; appreciable errors of parallax are consequently not probable.

The surface-temperatures were taken by the Cadets. Most temperatures taken with the automatic water-bottle were read off and entered in the journal by the two petty officers Adolf Johansen and N. A. Nilsen. All readings of the reversing thermometers were taken by me.

The temperatures of the sea-surface were taken with an ordinary thermometer immersed in water taken up in a water bucket.

The thermometers used for the automatic water-bottle were from Gustav Müller, Ilmenau i. Th. They were made of "Jena Normal glass 16^{III}". Their scales had not been specially tested, but as these scales were well made on the whole, and showed, whenever occasional tests were made, no errors exceeding 0.1° C., the temperatures of the Table may be considered trustworthy as far as the readings go.

The three Richter reversing thermometers, always used with the stop-cock water-bottles No. I and II and the reversing water-bottle, had been tested at the German Reichsanstalt in Charlottenburg in March 1909, and had got their corrections determined, as usual in accordance with the indications of the hydrogen thermometer. Their number received at the Reichsanstalt were: P. T. R. 37544 used in the reversing stop-cock water-bottle; P. T. R. 37547 used in the Pettersson-Nansen water-bottle and in the stop-cock water-bottle No. II; P. T. R. 37552 used in the stop-cock water-bottle No. I.

The temperatures given in the Table have been corrected for the errors of the scale and the freezing-point corrections and, in the case

of the Pettersson-Nansen insulating water-bottle, also for the adiabatic cooling. The readings of the Richter reversing thermometers have also been corrected for the thermic expansion of the broken off mercury after the reversion of the thermometer. The latter corrections were computed for each thermometer from the volume of the mercury broken off at 0°C .

Fig. 2. Vertical Curves of Temperature (broken line), Salinity (unbroken line) and Density (dotted line), at Station 3. In curves of temperature and density, a black dot indicates observations with the automatic water-bottle, a ring observations with the Pettersson-Nansen water-bottle, a cross observations with the reversing water-bottle. In the curve of salinity, a black dot indicates salinities obtained by single titrations, a cross by several titrations, an asterisk salinities obtained both by titrations and interferometer.

The accuracy of the values of temperature thus obtained by the reversing thermometers employed, may in most cases be expected to be within $\pm 0.01^{\circ}\text{C}$. The readings of the reversing thermometer No. 37544, used in the reversing water-bottle, exhibit, however, somewhat strange irregularities at Station 3 and 4, as is demonstrated by the vertical temperature curves of these stations (see Figs. 2 and 3). The upper parts of these curves, above depths of 400 (Station 4) and

600 metres (Station 3), where the temperatures were taken with the automatic water-bottle or the Pettersson-Nansen insulating water-bottle, have regular shapes similar to the forms of the curves of the other stations in the neighbourhood (cf. those of Stations 1, 2, and 5, in Fig. 15), their very regular slopes lying between that of the curve

Fig. 3. Vertical Curves of Temperature (broken line), Salinity (unbroken line) and Density (dotted line) at Station 4. Dots, crosses, and asterisks have the same meaning as in Fig. 2. The Densities given in the uppermost line above are 0.10 too low, 27.90 = 28.00 and 27.10 = 27.20.

of Station 1 and those of Stations 2 and 5. But where the temperature-readings taken with the reversing thermometer No. 37544, and the reversing water-bottle, come in, the curves have sudden, irregular bends which render these curves quite different from those of all other stations on this cruise (cf. Figs. 15, 37, 38). If there were an intermediate warm layer, with a secondary temperature maximum, at these

stations, it might seem a strange accident that at both stations this maximum should happen to occur just at the depth where the reversing thermometer and the reversing water-bottle began to be used, and at different depths at each station: at 800 metres at Station 3, and at 600 metres at Station 4. If it could be assumed that the reversing thermometer had given erroneous readings on these occasion, that would be the simplest explanation. But it is not probable. I have this thermometer still, and have never noticed any irregularities in its readings, and besides, the apparent irregularities in the vertical distribution of temperature at Stations 3 and 4 agree with similar irregularities in the vertical distribution of the salinity, as a comparison between the vertical curves of temperature and salinity will show (see Figs. 2 and 3). If there are errors, we would have to assume that the temperatures as well as the salinities at those depths are erroneous, and that consequently the reversing water-bottle has been closed, at some other depth. The fact that the vertical distribution of density at the two stations exhibits similar irregularities (see the curves Figs. 2 and 3) might seem to indicate that something of the kind has happened. It seems for instance improbable that at Station 4, there should have been a density of 27.33 at 600 metres and a density of 27.40 at 407 metres. And besides the density at 600 metres differs strikingly from all other densities found at the same depth at other stations (see Fig. 17). A plausible explanation would seem to be that the water-bottle has been reversed at some higher level. But it is extremely difficult to understand how such a thing could have happened. The bottle was released by messenger, and its releasing arrangement was very reliable, during three summers work, it has never once in my experience failed. At Stations 3 and 4, the bottle was attached near the end of the line, and no other instrument was used on the line simultaneously. The only conceivable possibility of an accident of the kind might be, that some bend or kink on the line has stopped the messenger for a while, and that it has fallen later during the hauling up. But I never noticed anything of the kind on the line which had been examined before use.

On the other hand the observations taken with the automatic and the Pettersson-Nansen water-bottle at 400 and 450 metres at Stations 2, 3, 4, 5 and 6, give higher temperatures and also higher salinities at Stations 3 and 4 than on the sides, at Stations 2 and 5 and 6 (see Fig. 15, and Section I, Fig. 6, and Pl. X), and these observations thus indicate a depression of the isotherm of 9°C (and also of the isohaline

of 35.30‰) at these stations. At 1000 metres, higher temperatures and salinities were also observed at Stations 3 and 4 than at Stations 2a and 5, indicating similar depressions of the isotherm of 8° C, and the isohaline of 35.20‰ (see Section I) in the middle of the channel. All these observations, taken with different instruments, seem therefore to agree fairly well. One might endeavour to explain this agreement by assuming that the reversing water-bottle, used also for 1000 metres, was reversed at some higher level at Stations 3 and 4, and not at Station 5; but we cannot possibly assume that similar irregularities have occurred with the automatic water-bottle and the Pettersson-Nansen water-bottles at 400 metres. The former bottle was released automatically and not by messenger. It would also be strange that there should have been such accidents with the reversing water-bottle at these two stations (only at 600, 800 and 1000 metres) while there is no indication of similar irregularities with this bottle at any of the numerous other stations, during the entire cruise.

From whatever side we look at these observations at 600, 800, and 1000 metres at Stations 3 and 4, it is difficult to arrive at any certain conclusion as to their trustworthiness. While the vertical distribution of density found, especially at Station 4 (600 metres), may seem highly improbable, it is difficult to understand how the observations can possibly be wrong. We must therefore regard the question as still undecided. It is a noteworthy fact that the shapes of the temperature curves of Stations 3 and 4 have on the whole great resemblance to the shapes of the curves from previous years (see Fig. 31—33).

In the instances given below, there is at any rate no possibility of the reversing water-bottle having been reversed at too high levels.

The vertical temperature curve of Station 12 (Figs. 37, 38) might seem to indicate that the reversing thermometer No. 37544 (used in the reversing water-bottle) has given a somewhat too low reading at 800 metres as compared with the readings of No. 37547 at 600 metres and of 37552 at 900 metres. But it has to be considered that there was a difference of an hour between the observations at 400, 600, 800 metres and at 900', 1090 and 1380 metres, and the ship may have drifted some distance in that time. The fact that the depth of 900 metres is only approximate (see the Table), and may consequently have been somewhat more or somewhat less, is of minor importance in this respect.

It may seem striking that the temperatures taken with No. 37544 (and the reversing water-bottle) at 1000 metres, especially at Stations 10,

11, 13, 14, 15 and 16, are so much lower than those taken with No. 37547 at 600 metres at the same stations, and also are much lower than those taken with Nos. 37552 and 37547 at 900 and 1090 metres at Station 12. There seems, however, to be a certain regularity in this; the temperature at 1000 metres is evidently falling westwards and with decreasing salinities from Station 8 to Station 11 (see Pl. X). Then it rises to the most western station, Station 12. But from this station it again falls north-eastwards with decreasing salinities to Station 15, then rises with increasing salinity to Station 16 (see Pl. XII).

There is, however, this to be noticed that while the salinities were found to be nearly alike (35.08, 35.09, and 35.08‰) at 1090 metres at Station 12, and at 1000 metres at Stations 11 and 13, the observed temperature was higher at the first station (6.55° C.), where it was taken with the thermometer No. 37547, than at the two latter stations (5.64 and 5.77° C.) where they were taken with thermometer No. 37544.

The observations at 600 metres at Station 17 (7.04° C., 35.10‰), where the temperature was taken with No. 37547, might seem to indicate that in this region of the sea the isotherm of 7° C. very closely follows the isohaline of 35.10‰. This would agree with the observation at Station 12, but not with those at Stations 11 and 13, which might seem to indicate that the temperature-readings at the two latter stations had been too low.

But a conclusion such as this would not be permissible, because the temperature of water with the same salinity may vary somewhat at different stations. At 1000 metres, at Stations 2 and 5 in the Rockall Channel (Pl. X), the observed salinities are 35.17 and 35.175‰, and the temperatures 6.45° C. and 6.51° C., the former temperature having been taken with the thermometer No. 37547 and the latter with No. 37544. At 300 metres at Station 18, a salinity of 35.15‰ and a temperature of 6.95° C. were observed with the automatic water-bottle. There seems to be no good ground for doubting the correctness of the readings of No. 37544 at Stations 8—16.

In some cases, the temperatures taken with the automatic insulating water-bottle, may seem somewhat improbable, as they give too low or too high densities. As examples may be mentioned the temperatures near Station 1, at 120 and 160 metres (see Table) near Station 13 at 102 metres (see Fig. 38), at Station 14 at 100 and 200 metres (see Fig. 38). Sometimes, where the temperatures are too high and the densities consequently too low, there is the possibility that the water-bottle might

have been closed by some accident at some higher level, while it was being let out, though this could not easily happen owing to the special construction of the bottle. Where the temperatures are comparatively low, this explanation will not hold good. There is then the possibility of there being some mistake in the reading, and this has evidently sometimes happened, *e. g.* 8.4° C. has been written instead of 9.4° C. But, where similar low temperatures have been observed at similar depths in the neighbourhood, it cannot be supposed that there should have been similar accidental mistakes in all these observations; see, for instance, the above mentioned observations near Station 14.¹⁾ It has also to be remembered that the observations were taken while the ship was under way, and consequently not at the same place, there may thus be a horizontal distance of more than a mile between two observations taken at an interval of ten minutes, and it may then be very possible that an observation gives lighter water than the previous observation, though the depth is greater.

The above experiences prove clearly how very desirable it is always to use two thermometers for the determination of the deep sea temperatures — either two reversing thermometers, or two thermometers for the insulating water-bottles, or the two kinds of thermometers combined. Had we had such double readings in the above cases there would have been no doubt as to their correctness. In order to be perfectly certain of the depth at which the water-bottles are closed and the thermometers reversed by the messengers, it is also very desirable to have a telephone connected with the sounding-line; by such an arrangement one can hear when the bottles are closed even at great depths. Then there could not easily be room for doubt as to the temperature observations, however astonishing they might be.

Water-Samples and Salinities.

All water-samples collected during the cruise were preserved in bottles with porcelain stoppers fitted with rubber washers and lever fastenings, so as to minimise the possibility of evaporation, except, as occurred in a few isolated cases, where the rubber washers were defective, or the bottle cracked. The bottles would hold 200 cc, some samples were preserved in greater bottles holding 500 cc.

¹⁾ There is, however, the possibility that a small quantity of mercury has been detached, and has been in the upper reservoir of the thermometer without having been noticed by the observer. But in that case all observations taken with the instrument during that time must be too low.

The surface-samples were collected by the cadets with an ordinary bucket. The water-samples taken with the automatic water-bottle were in most cases bottled by Mr. Adolf Johansen and Mr. N. A. Nilsen, while those taken with the other water-bottles were collected by me. Special care was taken to avoid the possibility of drops from outside the water-bottles coming into the glass-bottles along with the samples.

The Titrations of the water-samples have been carried out at the Biological Station of Bergen, under Dr. Björn Helland-Hansen's supervision, by Mr. Illit Gröndahl, some of them also by Helland-Hansen himself as a control, and some were made by Mr. T. Gaarder. A great many samples have been titrated twice, and where the results seemed more or less doubtful, or were of special interest, even more titrations have been made. As a rule the double titrations agreed well mutually. The titrations were checked in the ordinary way by Normal Water from the International Bureau in Copenhagen.

I have also examined a number of water-samples with the Interferometer constructed by Dr. Löwe (Carl Zeiß, Jena). Some of the samples of the deep-water, kept in bottles taking 500 cc, were used as standard water for the Interferometer. The salinity of these samples had been determined by a number (3—6) of titrations (Mohr's) by Helland-Hansen and Gröndahl. The determinations with the Interferometer gave a high degree of accuracy, the differences between two determinations of the same sample being as a rule less than 0.01‰. The results agreed on the whole well with those of the titrations.

IV. The deep Vertical Circulation of the Top Layers of the North-eastern North-Atlantic.

A striking feature of our vertical Sections I and II (Pls. IX—XIII) through the north-eastern regions of the North Atlantic, is the great uniformity in a vertical direction of the salinity and the temperature, and consequently also the density, of the intermediate layers, between the levels of, say, 100 metres and 600 or 800 metres. This uniformity is obviously to a great extent due to the vertical circulation, caused by the cooling of the sea-surface during the preceding winter. The effect of this circulation was in the beginning of July naturally less marked in the upper layers of the sea, between the surface and 100 metres, which had been much heated by the sun during the spring and first part of the summer.

Variations in Salinity due to Vertical Circulation.

The salinity of the top layers of the North Atlantic, affected by this vertical circulation, decreases gradually northwards, not only in a north-westerly direction, towards Iceland and Greenland, where the decrease is most rapid, but also towards the north-east, in which direction the water masses are supposed to travel. This decrease of the salinity, especially in the latter case, can only to a very limited extent be due to coastal (or arctic and polar) water, spreading over the surface of the ocean from its border regions.

The northward decrease of the salinity of the top-layers of the open North Atlantic, specially in the "Gulf Stream", must therefore chiefly spring from two sources: 1. the gradual intermixture with the underlying fresher water-strata, and 2. the precipitation on the sea-surface.

It is obvious that the water-strata of the lower part of a current moving along, will gradually be intermixed with water from underlying strata moving with different velocities or in other directions. Where the velocities of the movements of the strata are decreasing or increasing vertically, waves and very active, vertical vortex-movements will be created by which the waters of the strata are gradually intermixed; and the greater the difference of velocity and the smaller the differences of density of the strata, the greater these vertical movements and the more rapid the intermingling of the strata.¹⁾

¹⁾ It should also be taken into consideration that in the case of deep currents being created by the wind, there is a tendency towards a vertical circulation between the deep strata and the surface strata. Owing to the influence of the Earth's rotation, the current on the sea surface will be deflected to the right of the direction of the wind, the current in the underlying stratum will be still more deflected to the right, etc., so that the angle of deflection will increase with the depth downwards to a certain limit [see Nansen, 1902, p. 369 *et seq.*]. If there is a coast on the right hand side (or the left) of such a drift-current, or if there is a resistance in the sea by water moving in different directions, the water must be stored up on the right hand side of the drift-current. By his masterly mathematical discussion of the problem, Prof. V. Walfrid-Ekman [1905, 1906] has proved that in this case, and provided that the sea is sufficiently deep, and the sea-water is homogeneous, the consequent current may be divided into three different kinds: a surface current (with velocities decreasing downwards) running obliquely towards the coast (or the line of resistance in the open sea) if it is on the right hand side, or obliquely from it if it is on the left hand side; a midwater current of almost uniform velocity, running parallel to the coast (or the line of resistance); and a bottom current with velocities decreasing towards the bottom, running on the whole obliquely from the

There is another agency which helps this process. By the intermixture of the overlying warmer and saltier water with the underlying colder and less saline water, having approximately the same density, the water will contract slightly, and the resulting water will have a somewhat higher density than each of the original waters [cf. F. Witte, 1910, p. 223]. The consequence is that the intermixed sea-water will sink, and has to be replaced by water rising from below. But this rising water will again be intermixed and has to sink again in its turn, and so on. It is self-evident that this agency will accelerate the process of intermixture, always observed in the lower strata of a current.

Where the salinity of the water-strata below the top-layers, decreases vertically with the depth, the intermixing process will naturally have a tendency towards producing a gradual upward decrease of the salinity of the top-layers and an increase of the salinity of the underlying water. By the continuous vertical intermixture of the strata thus created, the upward decrease of the salinity may gradually reach

coast (or line of resistance) if it is on the right hand side; or towards it if it is on the left hand side.

The surface current and the bottom current have the same depth, which is equal to what Ekman calls the "Depth of the Wind Current", or the "Depth of Frictional Influence".

As the surface current and the bottom current carry water in opposite directions in relation to the coast, (or to the line of resistance in the open sea) it is obvious that water from the one current must in some way or other restore the water of the other carried in opposite direction, and there must consequently be some kind of vertical circulation between the water-masses carried by the two currents.

In reality, the conditions in the sea are not so simple as above assumed. As a rule, the sea-water is not homogeneous, but its density is increasing from the sea surface towards the bottom, and this will, as shown by Ekman, greatly influence the velocities, directions, and the whole nature of the currents created by the winds. According to what has been said above, it seems, however, evident that there will be a certain tendency in any current created by the wind, towards making the sea-water homogeneous in all depths reached by it. This may first result in a tendency towards dividing the water into more or less homogeneous strata, where there is, in each stratum, circulation between its upper and lower part. But then there will also be a tendency towards intermixing the lower strata with the upper ones, in order to approach the conditions of a homogeneous sea. In this manner the wind may, to some extent, have a stirring effect down to greater depths than might seem probable at a first glance.

The fact that, owing to the tidal wave, the directions and velocities of the currents are continually changing at all depths in the ocean, may also be of some importance for the stirring and intermixture of the strata.

the surface-layers of the sea. In this respect the convection currents, caused by the cooling of the surface during the winter, may be of special importance; for where they reach sufficiently deep strata, they may carry the intermixed water from below to the surface, and thus even the surface salinity may be reduced by the intermixture with the underlying water-strata.

But the gradual reduction of the salinity of the surface-layers of the Ocean, thus produced, will, as a rule, be considerably less than that caused directly by the precipitation on the sea-surface, in all regions of the Ocean where the annual precipitation is in excess of the annual evaporation of water from the surface.

Where the reduction of the surface-salinities thus occasioned is considerable and occurs rapidly, it may create surface layers which owing to their low salinity have a so much lower density than the underlying strata that they form a very great impediment to the vertical circulation, and thus afford a protection against cooling for the underlying water-masses.

But, in the North Atlantic, the dilution of the salinity of the seawater by the precipitation proceeds, as a rule, very gradually, and is to a considerable degree counteracted, and often neutralised, by the evaporation from the surface, especially in the summer. Therefore, it will not, as a rule, create surface layers with very much lower salinities than those of the underlying strata; and the differences of density, caused by the variations of salinity, will not offer any great hindrance to vertical movements causing a vertical intermixture of the top layers of this ocean, *e. g.* by wave action, by wind-currents causing vertical movements of various kinds, by tidal waves, etc. We may consequently expect that the convection currents, created by the cooling of the surface during the winter, may there reach greater depths than is generally the case in more northern latitudes, *e. g.* in the Norwegian Sea, where the cooling of the surface may be greater, but where the differences of salinity between the layers are comparatively still greater.

The so-called Vertical Convection Currents.

The great uniformity of the salinity and temperature of the water-strata down to 600 or 800 metres in our Sections I and II is therefore just what might be expected. In the Rockall Channel (see Section I, Pl. X) the uniform salinity is about 35.35‰, and in the North Atlantic west of the Rockall Bank first about 35.30‰ and then

further west about 35.25‰ (cf. Stations 10 and 11). In the sea south of Iceland, in Section II (Pl. XII), the uniform salinity is about 35.17‰ .

Similar conditions were observed by the Danish oceanographers in the sea south of Iceland in 1903, 1904, and 1905, and it was pointed out by Mr. J. N. Nielsen [1907, p. 10 *et seq.*] that the convection currents during the winter may reach as deep as nearly 800 metres.¹⁾

The convection currents have evidently reached depths of 600 metres and more in that part of the North Atlantic examined during our cruise.

The terms: vertical circulation and vertical convection currents, are strictly speaking not correct, and may easily lead to the misconception that these currents or motions always move up and down in a vertical direction; and this again leads to the erroneous conclusion that the vertical circulation always tends to create perfect uniformity vertically, between the surface and the depth reached by the convection currents.

By considering the real conditions in the sea it is, however, easily seen that the direction of the convection currents may frequently differ considerably from the vertical. The cooling of the surface during the winter will very rarely be exactly the same in two neighbouring areas of the sea, in the one the surface-water will, as a rule, become colder and heavier than in the other. Take as an example the Stations 13 and 14 in Section II (Pls. XII, XIII). If now the convection currents move only up and down in a strictly vertical direction, this would result in the creation of nearly perfect uniformity in the salinity and the density of all strata between the surface and the depth of the currents; but this uniform density would not be the same in both areas, the water-masses of the one would be heavier than those of the other at all levels of the vertical uniformity. There would consequently not be equilibrium: the heavier uniform water-column would have a tendency to sink in under the lighter uniform water-column which on the other hand would have a tendency to overflow the heavier water-masses. The vertical uniformity of density would thus be disturbed and we would find lighter water-strata with somewhat higher temperatures and

¹⁾ Regarding the vertical circulation of the sea, see Krümmel, 1907, s. 393; J. Gehrke, 1910, p. 66 *et seq.*, and 1912; L. de Marchi, 1912. As to the effect of the vertical circulation of northern seas, see Nansen, 1906, p. 85 *et seq.*, Helland-Hansen and Nansen, 1909, p. 227 *et seq.*

perhaps higher salinities near the surface, and with somewhat heavier water below.

These are therefore the conditions which we may expect, and which we also actually do find in the Ocean, even at the end of the winter. We may in fact expect that the cooled heavy surface water will comparatively rarely sink strictly vertically. In most cases it will sink obliquely, often at a slight angle to the horizontal, towards intermediate water-strata of a neighbouring area where the density is slightly lower, and the sinking water will be replaced at the surface by water from this same area, or also from some other region in the neighbourhood. During the summer the top layers of the sea are continually heated by the sun, and the vertical difference of temperature and density is much increased.¹⁾

The Effect of the Deep Vertical Circulation upon the Climate.

It is obvious that the deep vertical circulation during the winter in the North Atlantic is of great importance for the heating of the atmosphere of this region during the winter: By the deep circulation the sea is much cooled to considerable depths, and on the other hand, a very great volume of water comes in contact with the surface and gives off heat to the atmosphere.

If this sea had been covered by surface layers with salinities much lower than those of the underlying strata, the convection currents would not be able to penetrate far downwards; much less water would then come in contact with the surface, much less heat would be given off to the atmosphere, the light surface-layer of the sea would be-

¹⁾ Mr. J. N. Nielsen [1907, p. 11] will explain the decrease of temperature downward, observed in the summer south of Iceland, by the horizontal currents, the velocity of which he supposes to be greatest at the surface and to decrease with the depth. By these currents, the water near the surface should be replaced by warmer water (from more southern latitudes) more rapidly than at greater depths, and thus a rise of the temperature upwards should be accounted for. I find very little in Mr. Nielsen's own sections to support his views. If the isopycnals of his sections I, II, and IV be drawn, they hardly indicate that his horizontal currents south of Iceland move with velocities which are greatest at the surface and decrease with the depth, unless perhaps they be pure drift currents, created exclusively by the wind. On the whole, the horizontal movements of the water of this region are apparently very slow. Mr. Nielsen's explanation would also require that the water masses of the various strata were transported by the horizontal currents with velocities which would have to be much greater than what we are entitled to assume.

come much colder, while the underlying watermasses would be more or less protected by this lighter surface layer, and be less cooled. The result would be a considerably colder winter-climate, with a colder sea-surface in the winter, but a warmer ocean under the surface-layer.

The Penetration of the Heat from the Sun towards the Depth.

In the spring, as soon as the sun begins to heat the sea surface more than it is cooled by the emission of heat during the night, and when the atmosphere is beginning to acquire higher temperatures than the sea, the temperatures of the surface layers will begin to rise appreciably above those of the underlying strata. The depth to which this heating of the surface layers penetrates during the summer, not only depends on the depth to which the heat-rays of the sun penetrate into the water; but the more or less vertical movements (wave movements, vortex-movements, etc.) by which the strata are intermixed with each other vertically, or their particles are brought in contact with each other, are of great importance in this respect.¹⁾

In our Sections I and II (Pls. X and XII), from July 6th—12th, 1912, the surface heating has evidently penetrated beyond 100 metres in some places, but at the end of the summer it will naturally have reached a much greater depth.

It seems probable, that where the sea-water is very transparent, the direct absorption of heat from the sun's light-rays may be of importance for this summer-heating of the top layers of the ocean down to greater depths than generally admitted.²⁾

The depth to which the radiated heat of the sun may penetrate the ocean, has never been investigated by satisfactory methods, and we are still very ignorant on this point. Judging from the observations of Mr. A. v. Kolescinsky in some Hungarian salt-lakes Mr. J. P. Jacobsen [1908, p. 22] came to the conclusion that the heat-rays of the sun are practically absorbed before they penetrate 3 metres below the sea-surface, and that the solar rays will not directly produce any heating of importance at much greater depths. Dr. Björn Helland-Hansen's [1907, 1908] investigations of the oyster-basins of Norway seem, however, to prove that a heating to the extent of several degrees may

¹⁾ This vertical intermixture of the strata and its importance for the vertical conduction of heat has been very ably discussed by Dr. J. Gehrke [1912].

²⁾ See the investigations of Aimé, Jos. Luksch, Fol and Sarasin, Petersen, and others; also Krümmel, 1907, p. 388 *et seq.*

be produced during the summer by direct absorption of the solar rays at even greater depths than 10 metres; for the great rise of temperature during the summer, even at 10 and 11 metres, in these enclosed basins, in which the rapid increase of salinity and density from the surface downwards forms a great obstacle to vertical movements and intermixture of the strata, must chiefly be explained in this manner. It must also be remembered that the penetration of the sun's rays through the water of these basins is much hindered by the great quantity of plankton. Dr. Helland-Hansen's interesting observations during Murray's and Hjort's expedition in the Michael Sars in 1910, prove that a great deal of solar light-rays penetrate to greater depths than 1000 metres. The energy carried by these rays penetrating so deep, will not, however, be able to produce much heat by absorption, but it seems probable that, *e. g.* at 200 metres, the heating caused directly by the absorption of the sun's rays during the summer, may still be appreciable, where the transparency of the seawater is not too much disturbed by the plankton or by other undissolved matter.

It is naturally of much importance that while the heat of the sun's rays is gradually absorbed by the water strata through which the rays pass, there is no appreciable emission of this absorbed heat from the strata, because the dark heat-rays cannot penetrate much water before they are entirely absorbed, and the conduction of heat through water is so slow that it may be left out of consideration. The result must be a gradual accumulation of absorbed heat in these water-strata during the summer, as long as the altitude of the sun above the horizon is sufficient for its rays to reach the strata.

Seasonal Variation of the Surface-Salinity owing to Precipitation and Vertical Circulation.

In the region of the North Atlantic, traversed during our cruise, the precipitation is greater than the evaporation of water from the sea-surface. This is the case not only during the winter, but evidently also, on the average, during the summer. The result must be that in the course of the summer the heated surface-layers will gradually get lower salinities than the underlying colder and therefore heavier strata, with which they are only very slowly intermixed, owing to the difference of density. The difference of salinity thus produced will naturally be greatest at the end of the summer. During comparatively dry periods, in the first part of the summer, there may still be very little difference, as in our sections; or an increase of the sali-

nity of the surface-layer may even occur, owing to the evaporation being in excess of the precipitation.

But the average result of the summer must evidently, as a rule, be an appreciable reduction of the salinity of the surface layer towards the autumn. This is for instance obviously the explanation why Mr. Donald J. Matthews [1907, p. 285] found in September, 1905, "a remarkably well marked period of low (surface-)salinity over "the whole of the North Atlantic, the values reaching a minimum in "all places except on the northerly course of the Copenhagen-New York "liners, where the fall continued until the following month", and in September, 1904, there was evidently also a period of low salinity according to the investigations of Matthews, while in the winter the surface-salinities were on the whole comparatively high.

During the winter the difference in salinity between the surface-layers and the deeper layers, existing in the autumn, is again gradually obliterated by the vertical circulation, causing a gradual intermixture of the surface-layers with the underlying strata.

The result is that, in the region mentioned, the sea-surface has its maximum salinity at the end of the winter or in the spring, and its minimum salinity at the end of the summer or in the autumn.¹⁾ But the mean salinity of the whole of these upper water-strata of the sea, in which the vertical circulation takes place, will be reduced by the precipitation for each year.

The great seasonal variations in the lateral distribution of the coast water and the Atlantic water, caused by the variations in density of the water [cf. Nansen, 1902, p. 398; Helland-Hansen and Nansen, 1909, p. 229], will naturally also cause variations in the surface-layers in those regions of the sea which are near coastal currents. When the coast-water, with comparatively low salinity, becomes lighter, by heating during the summer, it will spread further seawards than in

¹⁾ Prof. Martin Knudsen has found that in the area between Latitude 59° and 61° N. and between Longitude 3° and 21° W. there is a seasonal variation in the surface-salinity of the sea, with a maximum in May and a minimum in September. He suggests that the most probable explanation of this periodical variation would be, that the Gulf Stream has a maximum velocity in the spring and a minimum period in the autumn, though he considers more observations in lower latitudes to be necessary „to give a final answer to this question“ [M. Knudsen, 1905, p. 9—10]. In my opinion, it is self-evident that the dilution of the surface-water due to the precipitation during the summer in connection with the vertical circulation during the winter, as described above, gives the simplest explanation of this seasonal variation.

the winter, and the Atlantic water in that region will then be covered with a warm layer of less saline water. There are possibly indications of such a seaward extension of the coast-water in the region of Station 3, in Section I, where the surface-layer, with salinities below 35.3‰, may have been intermixed with water which, by some vortex-movement, has been carried seawards from the coast water.

Water over Banks in the Ocean.

Where the depth of the sea is less than that to which the convection currents, caused by the cooling of the sea-surface, are able to reach down, the cooling during the winter will naturally have a tendency towards producing a nearly homogeneous mass of water between the surface and the bottom. If the horizontal circulation be sufficiently rapid, the water of the strata may be continually renewed before the uniformity is attained; but generally the horizontal circulation is not very active over the banks, the water-masses being there as a rule comparatively stationary, owing to the resistance offered by the sea-bottom to the horizontal movements of the water.

As there is a thinner layer of water to be cooled over a bank than over the deep sea, it is also obvious that the cooling during the winter must there make the water colder (and consequently also heavier) than in the surrounding deeper regions [see Nansen, 1906, p. 30 *et seq.*; Nielsen, 1907, p. 12], and the shallower the sea the colder the water.

If the precipitation over such a shallow area be the same as over the surrounding sea, it will obviously have a tendency towards making the salinity of the nearly homogeneous water of this area somewhat lower than what is found in the deeper sea, because in the shallow sea the convection currents will intermix the same quantity of rain-water with a much smaller volume of sea-water. The comparative reduction of the salinity of the bank water thus produced by the vertical convection currents, may to some extent be counteracted by the fact that over the banks there will be very little reduction of the salinity from below, by intermixture with water from the deep strata. In regions of the ocean where the evaporation from the surface is in excess of the precipitation, this may lead to the result that at the end of the winter the water over the banks has a somewhat higher salinity with a lower temperature than the surface-layers of the surrounding deeper sea, where the salinity has been reduced by water brought up from below by the vertical convection currents. In regions where the precipitation is appreciably in excess of the evaporation, it will, how-

ever, be the other way, the water over the banks will at the end of the winter have a somewhat lower salinity than found at the same levels in the surrounding sea.

But in spite of this small reduction of the salinity, the bank-water will become heavier than the surrounding water at the same levels, and will therefore sink down along the slopes on the sides of the bank. We must consequently expect to find comparatively cold and heavy water with somewhat low salinities near the slopes of such banks in the latter part of the winter.

The bottom-layer of comparatively cold and heavy water with a somewhat reduced salinity, resting over the Rockall Bank in Section I (Pl. X), is obviously such "winter water", formed by the cooling during the previous winter. This layer was on July 8th about 100 metres thick, filling the space between a depth of less than 100 metres and the bottom. It had a nearly uniform salinity of about 35.3‰ and a fairly uniform temperature of about 8.6° C. Salinity and temperature were somewhat lower on the western side of the bank.

This nearly homogeneous mass of water had certainly filled the whole space over the bank, up to the sea-surface, at the end of the winter, when the cooling of the surface was still going on, and the water was consequently continually becoming heavier. But when the cooling stopped, or the surface-water was even gradually heated, this mass of comparatively cold water (with temperatures of about 8.6° C and even 8.2° C), resting over the Rockall Bank, was heavier than the water at corresponding levels on both sides of the bank, and as there is no sufficient force to keep it in place, it must consequently sink towards a position of equilibrium, and is gradually replaced near the surface by water from the sides, in a similar manner as the heavy water in the sea north of Jan Mayen, where the deep-water is formed during the winter [cf. Nansen, 1906, p. 88 *et seq.*].

When our observations were taken on July 8th, 1910, the homogeneous heavy water of the Rockall Bank had sunk down to about 100 metres, while near the surface, down to 50 and 60 metres, there was water with much higher temperatures. At the end of the summer we may expect to find very little, if any, of this winter-water left over the bank, unless there be a sufficiently strong cyclonic vortex-motion round this area, to keep the heavy water at such a high level in its central part.

The heavy water evidently sinks down along the slopes on both sides in Section I (Fig. 6, Pl. X), eastwards into the Rockall Channel,

and westwards into the Atlantic, where water with very nearly the same temperature (about 8.5°C) and salinity (about 35.3‰) occurs near the slopes at 400 and 600 metres. This explains the shape of the isopycnal of 27.40, sloping down on both sides of the bank, more or less parallel to the bottom, and it explains why the density is so very nearly uniform ($\sigma_t =$ about 27.45) down to great depths along both slopes. The water found at 400 and 600 metres at Station 2, and at 600 metres at Station 3, in the Rockall Channel, may even be water of this kind which by some vortex-motion in the channel has been carried over towards its eastern side. By intermixture with underlying waters, the temperature and salinity may be somewhat reduced (*e.g.* to 8.27°C and 35.26‰ at 600 metres at Stat. 2).¹⁾

The correctness of the above view as to the formation of layers of comparatively cold water, with comparatively low salinity, over the banks of the ocean during the winter, is strongly supported by Capt. Amundsen's sections taken onboard the Fram across the Porcupine Bank and the Rockall Bank in June and July 1910 (see Figs. 4 and 11, p. 28 and 34).

The comparatively low temperature of the water (about 8°C) near the bottom on the Rockall Bank was actually demonstrated as early as 1869 by some bottom-temperatures taken during the Porcupine Expedition at Station 24 (at 109 fathoms or 199 metres, see Fig. 5, p. 29), and Station 25 (at 164 fathoms or 300 metres) about the 1st July 1869. The bottom-temperatures were there 8.0°C and 8.1°C [cf. C. W. Thomson, 1874, p. 142], while the temperature at the same levels in the channel was much above 9°C (see Fig. 5, p. 29). At Station 23a, on the eastern slope of the bank the bottom-temperature at 768 metres (420 fathoms) was 8.0°C , while at Station 23 where the depth was greater, the temperature was 8.6°C at 732 metres (400 fathoms). The colder bottom-water at Station 23a had probably sunk down along the slope from the bank.

¹⁾ After the above had been written, I received Prof. Martin Knudsen's paper on the "Danish Hydrographical Investigations at the Faroe Islands in the Spring of 1910" in which he also mentions the water volumes with comparatively low temperatures and salinities which have been observed on the Faeroe Bank as well as on the Rockall Bank [1911, p. 7 *et seq.*]. He thinks that this water may arise by intermixture with colder and less saline water which is carried by currents along the slopes upwards to the banks from the deeper layers on the sides. He does not explain what kind of upward currents these may be, or how they are formed. The explanation given above is certainly more natural, it is simply winter-water resting over the banks, and sinking down along their side-slopes.

The comparatively cold water with temperatures between 8.0 and 9.0° C, and with salinity below 35.30‰ on the Rockall Bank and its slopes is also demonstrated by the Danish observations during the cruise of the *Thor* in that region in May 1908 [cf. Bull. Trimest. 1907—08], see Figs. 7 and 14, p. 31 and 39. The Danish Section (Fig. 7) across the Rockall Channel may, however, give the impression that there was then little of this bank-water on the eastern slope of the bank, towards the channel, while there was the more on the western slope, where no water with salinity above 35.30‰ was observed.

The surface of the shallow sea over the continental shelf off Ireland, is covered by coast-water with a comparatively low salinity. The cooling during the winter cannot therefore produce heavy winter-water similar to that farther seawards. But over the continental slope the convection currents may reach greater depths during the winter, causing a fairly uniform vertical distribution of salinity down to 600 and 800 metres; and the vertical circulation may thus even here have a tendency to lower somewhat the temperature and the salinity of the water, where the sea is shallower.

V. The Rockall Channel and the Irish Current.

Section I (Pls. IX—XI) across the Rockall Channel and the Rockall Bank, traverses the so-called „Gulf Stream“, which may be called the Irish Current, as proposed by Prof. Krümmel. Its waters are easily distinguished by their comparatively high salinities and temperatures. The shape of the isohaline of 35.30‰, and partly that of 35.20‰, and of the isotherm of 9° C, and partly that of 8° C, are specially characteristic in this respect. On the whole they slope much eastwards in the section, thus indicating that, owing to the Earth's rotation, the current is deflected eastwards towards the continental slope off the British Isles, and it follows this slope on its north-eastward course. The section proves that the greater part of the water-masses, carried north-eastwards by the Irish Current, passes through the Rockall Channel, between the continental shelf off Ireland and the Rockall Bank, while only a very small portion of the water with the highest salinities (above 35.30‰) occurs west of the Rockall Bank, and seems to have no distinct northward movement.

It also becomes obvious that it is a continuation of this current through the Rockall Channel which flows through the Faeroe-Shetland

Channel. The chief part of the warm Atlantic water carried into the Norwegian Sea by the latter current must therefore have passed through the Rockall Channel.

The correctness of these conclusions is also fully confirmed by a comparative examination of the following sections: Amundsen's two sections (of June and July 1910)¹⁾ north and south of the Frithjof section (see Fig. 1, Sections A and B, and Figs. 4 & 11); two Danish sections taken onboard the Thor in May and June 1905 [cf. Nielsen,

Fig. 4. The southern Section of the Fram, June 1910, along the line A in Fig. 1, showing the vertical distribution of Temperature (the figures to the left of the vertical lines at the stations), Salinity (the figures to the right of the vertical lines), and Density (the figures under the above ones). Single shading indicates salinities between 35.30 and 35.40‰, cross shading salinity between 35.40 and 35.50‰, cross shading with vertical lines salinity above 35.50‰.

Horizontal Scale 1:6,000,000; Vertical Scale 1:10,000.

1907] in the region north of the Frithjof section, from the Hebrides towards the Rockall Bank (Figs. 1, E, and 8), and from Scotland north-westwards across the Faeroe Bank (Figs. 1, F, and 12); two sections through the Scottish observation stations taken north-west and west of the Hebrides in August 1910 (Figs. 1, C and D, 9 & 10)²⁾. The section

¹⁾ The oceanographic observations taken during Amundsen's cruise with the Fram in June and July 1910, will be described by Dr. B. Helland-Hansen and myself; but this work has not yet been finished.

²⁾ Cf. Bulletin Hydrographique pour 1910—1911. Conseil Permanent Intern. pour l'Explor. de la Mer, Copenhagen, 1912. Through Prof. Martin Knudsen's kindness, I have been able to study the Tables of this volume before it is published.

of the Rockall Channel taken during the Porcupine Expedition in 1869 (Figs. 1, P, and 5)¹⁾, and the Danish section of May 1908 (Figs. 1, H, and 7)²⁾ are also of much interest.

It is obviously the same kind of Atlantic water, with comparatively high temperatures and salinities, that is seen in all these sections. The inclinations of the isotherms and isohalines indicate that this water is deflected eastwards against the Porcupine Bank (Amundsen's Section A, Fig. 4) and the continental slope off Ireland and Scotland, and that the water is moving slowly northwards or north-eastwards along this slope. These conditions are particularly clearly demonstrated by Amundsen's southern Section (Fig. 4), the Frithjof Section I (Fig. 6), and the Danish Section F

¹⁾ Cf. Carpenter, Jeffreys, and Thomson 1870; Wyville Thomson, 1874.

²⁾ Cf. Bulletin Tri-mestriel, 1907—1908. Cons. Perm. Int. p. l'Expl. de la Mer, Copenhagen, 1909.

Fig. 5. Section of the Porcupine, June 1869, along the line P in Fig. 1. Explanation and Scales see Fig. 4.

(Fig. 12) which all run more or less transversally to the direction of the current, while Amundsen's northern section (Fig. 11) runs obliquely to that direction (see Fig. 1, B); this is also to some extent the case with the Danish Section E (Fig. 8) and the Scottish Section D (Fig. 10), which are moreover incomplete.

Fig. 6. Section I of the Frithjof, July 1910, along the line I in Fig. 1.

Explanation and Scales see Fig. 4.

The sections demonstrate the gradual decrease of the Salinities and the Temperatures during the northward flow of the water.

Salinity. In Amundsen's southern section, westwards from southern Ireland (Fig. 4) the salinity of all water is above 35.30‰ and to a great extent above 35.40‰ . There are even small volumes of water with salinities above 35.50‰ . It is, however, probable that

Fig. 7. Danish Section of May 1908, along the line H in Fig. 1.
Explanation and Scales see Fig. 4.

lower salinities, even below 35.30‰ would have occurred in the section if it had been continued farther westwards.

In the Frithjof section (Fig. 6), across the Rockall Channel from the shelf north of Ireland, the salinity of the water between the surface and 600 metres is chiefly between 35.30 and 35.37‰; there is only a small volume of water with a salinity of about 35.40‰, and there are no other traces of salinities approaching 35.50‰.

In Amundsen's northern section (Fig. 11), chiefly north of the Rockall Channel, the volume of the water with salinities above 35.30‰ has been much reduced. As the section runs obliquely to the direction of the current, this water has there a greater extension then would be the case in a transverse section, *e. g.* like the Danish Section F (Fig. 12). The salinities of Amundsen's section are on the whole comparatively low. There are, however, still slight traces of salinities above 35.40‰ at Stat. 22, in 35 and 40 metres.

The salinities of the Danish Section H (Fig. 7), of May 1908, are very similar to those of the Frithjof section. In the two Scottish Sections C and D (Figs. 9 and 10), of August 1910, the salinities are not much lower; but these short sections do not show the westward distribution of the waters of the Irish Current.

The Danish Section E (Fig. 8) is also incomplete; but the Section D (Fig. 12) is much longer and demonstrates a great reduction of the transversal extension of the water of above 35.30‰, to much less than the half

Fig. 8. Danish Section of June, 1905, along the line E in Fig. 1. Explanation and Scales see Fig. 4.

of what it is in the Frithjof section (compare Fig. 12 with Fig. 6); the current is evidently to a great extent formed by water which has a somewhat lower salinity. In the Faeroe-Shetland Channel the waters of the current have still lower salinities.

Some salinities of the two Danish sections E and F appear to be

somewhat high as compared with those of the Frithjof section and Amundsen's northern section, the salinities above 35.40‰ at the Danish Station 53 (Fig. 12) may be especially mentioned. The sali-

Fig. 9. Scottish Section of Aug. 1910, along the line C in Fig. 1. Explanation and Scales see Fig. 4.

Fig. 10. Scottish Section of Aug., 1910, along the line D in Fig. 1. Explanation and Scales see Fig. 4.

nities at Amundsen's Stations 23 and 22 (Fig. 11), just north of this station, were considerably lower. From a comparison of the Danish and the Norwegian observations, one might infer that the current has carried more saline water in May 1905, than in July 1910. This would

be in accordance with the fact that the water of the current was probably warmer in 1905 than in 1910, as will be mentioned later.¹⁾ It has, however, to be considered, that no certain conclusions of the kind may be drawn from sections where there are such great distances between the stations. Our Frithjof Section I proves how the vertical distribution of salinity and temperature may differ greatly at short distances (cf. Fig. 6, Stations 1, 2, and 3); and *e. g.* Amundsen's two Stations 22 and 23 (Fig. 11) were not so near the continental slope as

Fig. 11. The northern Section of the Fram, July, 1910, along the line B in Fig. 1. Explanation and Scales see Fig. 4.

the Danish Station 53 (Fig. 12). There is a remarkable resemblance between the salinities (35.41 and 35.39‰) of the latter station and those (35.39 and 35.41‰) of the Scottish Station Sc. H of August 22nd, 1910, in Section D (Fig. 10). The two stations have perfectly similar positions on the continental slope, the Scottish station some distance south-west of the Danish one (see Fig. 1). These two vertical series of observations may therefore naturally corroborate each other as to the accuracy of the determinations of salinity. But these values of salinity (about 35.40‰) are higher than those found near the continental slope in the Frithjof section, which were about 35.35 and

¹⁾ On a previous occasion [cf. Helland-Hansen and Nansen, 1909, p. 32] it was pointed out that the Danish determinations of the salinities of water-samples taken in May 1903, had a tendency towards giving higher values than the Norwegian titrations of samples taken practically simultaneously in the same regions. But this naturally does not involve there being a similar tendency in 1905.

35.37‰; and according to information that Dr. Hølland-Hansen has kindly given me, the latter values agree perfectly with the salinities found by his very careful observations at some stations of the Michael

Fig. 12. Danish Section of May, 1905, along the line F in Fig. 1.
Explanation and Scales see Fig. 4.

Sars (during the Murray-Hjort Expedition) of August 5th and 6th, 1910, in the Rockall Channel between the Frithjof stations and the Scottish stations. The highest salinity found by Helland-Hansen in the Channel was 35.37 ‰, and that was only observed once near the continental slope.

These observations have not, however, yet been published. The possibility that the Scottish salinities of August 1910, may to some extent be too high, is not excluded, considering that the Scottish series of observations from the Faeroe-Shetland Channel, taken in the same month, have often somewhat inaccurate values.

The Temperature of the Water gradually decreases northwards, as is clearly demonstrated by the sections. Let us first compare the sections from 1910.

In Amundsen's southern section (Fig. 4) the isotherm of the 10°C . descends to 450 and 500 metres. In the Frithjof section (Fig. 6) it is raised to between 50 and 100 metres, while the isotherm of 9°C . descends to 700 and 800 metres. Farther north, in the Scottish Sections C and D (Figs. 9 and 10) taken nearly seven weeks later, the isotherm of 9°C . is in about 400 or 500 metres, though the water strata above that level have been heated during the summer. In Amundsen's northern section (Fig. 11) the isotherm of 9°C . descends to 300 metres at Station 17 west of the Scottish Section D (see Fig. 1); but at the stations farther to the north-east, it lies between 100 and 200 metres.

The sections from earlier years exhibit very much the same decrease of temperature northward. The Porcupine section (Fig. 5) of June 1869, was taken some distance south of the Frithjof section (see Fig. 1, I and P). The temperatures at 250 fathoms (457 metres) of the former section are very like those at 400 metres of the latter. The temperatures at 500 fathoms (914 metres) of the Porcupine section are higher than those at 1000 metres of the the Frithjof section, and the isotherm of 8°C . seems to lie slightly lower.

In the Danish Sections H (Fig. 7), E (Fig. 8), and F (Fig. 12), of May 1908, June 1905, and May 1905, there is also a northward decrease of temperature. But the sections of different years are of course not quite comparable in this respect, as the temperature of the waters carried by the current varies from year to year; it is naturally also of importance in what month of the year the sections are taken. If *e. g.* the Danish Section H, of May 28—30, 1908, be compared with the Frithjof section, it is striking that, although it is farther north and was taken almost six weeks earlier in the season, its temperatures are not much lower, the isotherm of 9°C . is in about 500 metres, and the temperature at 1000 metres was even higher than at any of the Frithjof stations to the south. It gives the impression that the current was warmer in 1908 than in 1910. It has, however, to be considered

that in the region of Section H, the Rockall Channel is narrower than in the region of the Frithjof section. The northward flowing water may thus be somewhat more compressed in Section H.

In the Danish Section F (Fig. 12) the isotherm of 8°C . has very nearly taken the place of the isotherm of 9°C . in the Frithjof section; it descends almost to 900 metres near the continental slope. But as the current was probably warmer in 1905 than in 1910 (see later) the isotherm may not have descended so deep in the latter year as in the former.

Fig. 13 represents a longitudinal section along the Rockall Channel (see Fig. 1, Line L) through Station 12 of the Fram (Fig. 4), Stations 3 and 4 combined¹⁾ of the Frithjof Section (Fig. 6) the western station of the Scottish Section C (Fig. 9), the two most western stations combined of the Scottish Section D (Fig. 10), and Stations 21 and 22 combined of the northern Fram Section (Fig. 11). The section has also been continued across the Wyville Thomson Ridge and along the Faeroe-Shetland Channel, through the two Danish Stations of May 11, 1910,²⁾ the Scottish Stations 19 C and 14 A of May 1910,³⁾ and the Frithjof Station 46. This longitudinal section, along the Rockall Channel, demonstrates fairly well the vertical distribution of salinity and temperature (also density) along the axis of the current in the summer of 1910 (June, July, and August). It has, however, to be kept in view, that the observations at the Scottish Stations (Fig. 13, C and D) are taken more than a month and a half later than the others; owing to the heating during the summer, the temperatures of the surface-layers are comparatively higher, and their densities correspondingly lower, than those of the other stations from June and July 1910.

Owing to the great variations in temperature and salinity, often occurring at short horizontal distances in the transverse sections of a current (cf. Fig. 6), a longitudinal section may easily give misleading representations as to the distribution of temperature and salinity, if

¹⁾ The observations at the different depths at these two stations give very nearly the same mean values of temperature, salinity, and density, as the means of all Stations 1 to 5, which would naturally have given the most trustworthy representation of the waters of the current.

²⁾ See Bull. Hydrogr. 1909—1910. Copenhagen 1911, B. 1, p. 46.

³⁾ See Bull. Hydrogr. 1909—1910. The values of salinity obtained at the the two Scottish Stations 19 C and 14 A show very great irregularities, which seem to indicate that the determinations have been incorrect, and this is the reason why the shapes of the isohalines (especially of 35.20 and 35.10‰) are so irregular, differing so much from the shapes of the isotherms.

The best plan would naturally be to take, for each level, the means of the observations at all stations in each transverse section across the current; but this would require complete transverse sections.

Our section Fig. 13, is probably fairly representative. It exhibits the northward decrease of temperature and salinity, and the increase of density, which are demonstrated by the rise of the isotherms (the broken lines) of 12°C. , 10°C. , 9°C. , the isohalines (the unbroken lines) of 35.40 and 35.30‰ , and the isopycnals (the dotted lines) of 27.20, 27.30, 27.40, and 27.50‰ . The northward rise of the isohalines proves that during their northward course the waters in the underneath part of the current are gradually inter-mixed with the underlying strata, which have lower salinities and temperatures. The result is a lowering of the salinity, as well as temperature, of the overlying waters, while the salinity and temperature of the underlying waters may be increased.

This may, for instance, be the explanation why, at 1000 metres, the salinities are higher (35.25‰) at the Scottish stations (Fig. 13, C and D) than at the Frithjof stations (Fig. 13, F 3 & 4) farther south. It might also be expected that the temperatures would be higher, which they are not in Fig. 13; at the Stations 1 and 5 of the Frithjof Section (Fig. 6) there were, however, much lower temperatures (6.5°C.) at 1000 metres. It has also to be kept in mind that the vertical circulation during the winter, caused by the cooling of the sea surface, will lower the temperatures directly or indirectly to considerable depths,

Fig. 14. Danish Section of May, 1908, along the line K in Fig. 1. Explanation and Scales see Fig. 4.

during the northward course of the water-masses. As mentioned before, the vertical circulation in combination with the precipitation, will also gradually lower the salinity of the water-strata; but the steep rise of the isohalines, especially that of 35.30‰, may indicate that for the deeper strata this reduction is of less importance than that caused by the intermixture with the underlying waters. The oblique convection currents caused by the unequal cooling of the sea surface in neighbouring regions, as mentioned above (p. 19), may, however, also have some effect upon this northward rise of the isotherms and isohalines.

The comparatively rapid increase of the density of the waters during their northward course, demonstrated by the rise of the isopycnals, is due to the cooling of the sea-surface during the winter and the vertical-circulation thus produced. This horizontal distribution of density with isopycnals rising northwards along the Rockall Channel will naturally have a tendency to accelerate the northward flowing current. The rise of the isopycnals cannot in this case indicate an eastward movement of the waters, transversally to the section, because the waters must necessarily move through the channel, along and not against the continental slope.

Our longitudinal section (Fig. 13) along the Rockall Channel, and the various transverse sections demonstrate how misleading some current representations and descriptions of the movements of the water, really are. I may specially mention the German expressions „Auftriebwasser” and „Anstauungswasser” which may convey the idea of waters moving upwards and downwards as represented in Dr. G. Schotts sections of the Ocean [1902, Pls. XXVIII—XXXI]. Such ideas might lead to the conclusion that in the northern part of the longitudinal section of the Rockall Channel Fig. 13, there was an upward movement of cold water from below, while, in the southern part of the section, there was a downward movement of warm water from above. The movements must, however, go in the opposite direction; the cold water in the north has a tendency to sink and to be overflowed by the warmer water coming from the south, but which is gradually cooled on the way.

In transverse sections of currents, the differences in level of the cold and warm water-strata on both sides of a current, are of course as a rule not due to upward or downward movements of the cold and warm waters, for the strata in the sections may as a rule be very nearly in a state of lateral equilibrium, the differences of level being simply due to the effect upon the moving waters of the Earth's rotation.

Where the velocities of the current are decreasing from the surface-layers downwards, the moving strata must naturally slope transversally to the direction of the current, in the northern Hemisphere deepest on its right side, and in the southern Hemisphere *vice versa*.

The isohalines and isotherms of the surface chart and the charts, or horizontal sections, for the depths of 50, 100, 200, 300, 400 and 500 metres (Pls. II—VIII), give an idea of the motion of the waters through the Rockall Channel towards the Faeroe-Shetland Channel. These charts are based upon the observations taken during the cruise of the *Frithjof* as well as those taken almost simultaneously during Amundsen's cruise in the *Fram*, June 20th to July 7th, 1912. The Scottish observations in August 1910, at the stations marked with crosses, have also been used.

The Vertical and Horizontal Distribution of Temperature, Salinity, and Density in Section I, across the Rockall Channel.

The trustworthiness of the observations in the section of the Rockall Channel has already been discussed at length above (p. 9 *et seq.*). As was then pointed out, the vertical distribution of density, as given by the observations at Stations 3 and 4, especially at 600 and 800 metres, seems improbable, but on the other hand it is difficult to understand how these observations could be wrong, and besides, there is a certain agreement between them. It is also striking what a close resemblance there is on the whole between the vertical temperature curves of these stations and those of stations taken in the Rockall Channel in earlier years (see *infra*, Figs. 31, 33).

Fig. 15 represents the vertical curves of temperature at the different stations in the channel, Fig. 16 represents the corresponding curves of salinity, and Fig. 17 those of density. A distinction may be observed between two types of these curves, especially in the temperature and density curves. The temperature curves of Stations 2 and 5 represent the one type; they slope very regularly, and down to 1500 metres they practically concur. The salinity curves of these two stations also exhibit great similarity, as do the density curves. All these curves have, on the whole, very regular shapes with comparatively gradual slopes. The curves of Station 6 belong to the same type; they show comparatively cold water with high density, but with comparatively low salinity, as might be expected because the station was on the slope of the Rockall Bank and was influenced by the bank-water.

The other type is represented by the curves of Station 1, on the continental slope, which have much steeper gradients. They show colder water (bank-water) with a higher density in the top-layers, between the surface and about 250 metres. But below this level was warmer

Fig. 15. The Vertical Curves of Temperature at Stations 1—6 in the Rockall Channel. Black dot denotes observations obtained with automatic water-bottle, ring with the Pettersson-Nansen bottle, cross with the reversing bottle, asterisk with the stop-cock bottles (or at Station 2 the Pettersson-Nansen bottle with reserving thermometer).

water with lower densities, but higher salinities, than at Stations 2 and 5.

The curves of Stations 3 and 4 belong, on the whole, to the latter type. The curves of temperature and density of both stations are much alike. Their upper portions, above the level of 600 or 400 metres, slope regularly, at angles between those of the curves of Station 1, and those of Stations 2 and 5. Between 600 and 1000 metres their shapes

are very peculiar, but as regards their average gradients they resemble the curves of Station 1. Near 1500 metres and lower they again approach the curves of Stations 2 and 5.

It looks as if the curves of the latter type indicate a vertical circulation which has given them their steep gradients down to 800 and 1000 metres. They are in shape very like the curves of the Porcupine stations of 1869 and those of the Danish stations of 1905, 1906, and 1908 (see Figs. 31—33).

The curves of the former type (the Frithjof Stations 2 and 5) exhibit hardly any traces of a vertical circulation. It looks as if the cold water from below had been lifted sufficiently to almost obliterate the traces of the vertical circulation.

All temperature and density curves of our stations in the Rockall Channel demonstrate very conspicuously the effect of the heating to which the surface layers, down to about 100 metres, had been exposed during the spring and the first summer months of 1910. The salinity curves also demonstrate a commencing reduction of the salinity of the uppermost surface-layers. This reduction of the salinity would naturally be much more developed towards the autumn.

If we now look at the transverse Section I of the Rockall Channel (Fig. 6, and Pls. IX, X), we see that at Stations 2, 5 and 6 (with the curves of the first, regular type) the isohalines and isotherms rise fairly regularly to comparatively high levels, while the Stations 1, 3, and 4 (with curves of the second type) are near the depressions of the waves of the isotherms and isohalines; but, as mentioned before, the temperature curves of the latter stations have most resemblance to the curves of earlier years.

Fig. 16. The Vertical Curves of Salinity at Stats. 1—6. Dots, crosses and asterisks have same meaning as in Fig. 2.

The Horizontal Motion of the Water.

The isopycnals of Section I (Pls. XI and IX) across the Rockall Channel, may give some information about the horizontal movements of the water in this region. Provided that the average direction of the movements is approximately that of the channel, and is more or less perpendicular to the section, and provided that there was lateral equilibrium

Fig. 17. The Vertical Curves of Density (σ_t) at Stats. 1—6. Marks mean the same as in Fig. 15.

in the moving waters, the isopycnals prove that the average horizontal movement of water through the channel was very slow at the time the section was taken, unless the water at greater depths than 1500 metres flowed with considerable velocity in the same direction; which, however, is hardly probable.

The isopycnals of values between 26.70 and 27.30, in the strata between the surface and 100 metres, run more or less horizontally, and

instead of sloping towards the right side of the current they rise to higher levels over the shelf north of Ireland. Consequently, if there was lateral equilibrium in this part of the section, the velocities of the northwards moving current, whatever they may have been, were not decreasing from the surface downwards to below 100 metres at this place, unless there were a drift current, created exclusively by the wind in these upper layers. If, however, near the continental slope (Station 1), the northward movement was more rapid at 100 metres than near the surface, this would explain the rise of the isopycnals in this region. But the comparatively high densities of the top-layers at Station 1 may also be due to the cooled winter-water from the shelf, which is to some extent hindered from sinking down along the slope by the northward-moving water which, owing to the Earth's rotation, is deflected towards the right against the slope.

The isopycnal of 27.40 has a distinct inclination from about 100 metres over the Rockall Bank to about 640 metres at Station 1 near the continental slope on the right side of the current. Putting aside the great and peculiar undulations of this isopycnal, its inclination from the left towards the right indicates that the water of these strata was, on the whole, moving slowly northwards with velocities which decreased downwards from the level of about 250 metres. The rise of the isopycnal of 27.40 above the Rockall Bank is evidently due to the comparatively high density of the cooled winter-water of the bank (cf. above p. 25). This water is probably sinking slowly down along the side-slopes of the bank in the section, and the rise of the isopycnals in this region cannot therefore be taken as a certain indication of any horizontal movement, because the water-strata have probably not attained their lateral equilibrium near these slopes, *e. g.* at Stations 6 and 8. But at Station 5 the gradients of the isopycnals are probably not much affected by the sinking water nearer the slope.

The curves in Fig. 17 show that the vertical distribution of density was almost identical at Stations 2 and 5, below the level of about 250 metres. Above that level, the densities were somewhat higher at Station 2 than at Station 5. Provided the current in this region was chiefly created by difference of pressure, and not directly by the wind, that there was approximately lateral equilibrium in the section, and that the velocities of the horizontal water-movements were decreasing from 250 or 300 metres downwards, we may thus infer that, on the average, there was no transfer of water in a northerly direction between these two stations; *i. e.* if in one part of the section, *e. g.*

between Stations 4 and 5, the water was moving northwards this must have been compensated by a corresponding southward movement in another part, *e. g.* between Stations 2 and 3. Judging from Section I, the northward transport of water must then have occurred along chiefly the eastern side of the channel, between Station 2 and the continental slope.

It is in fact just what has been repeatedly observed in the Norwegian Sea, *viz.*: the sea currents run with their greatest velocities along the edges and slopes of the continental shelves; inside the edges their velocities are very small, and the velocities also decrease rapidly seawards from the slope. This was especially noticed along the edge of the submerged shelf off northeastern Greenland [cf. Helland-Hansen and Koefoed, 1909], off Norway [cf. Helland-Hansen and Nansen, 1909], and in the Faeroe-Shetland Channel.

On the Calculation of the Velocities of Ocean Currents.

Before we attempt to compute the velocities of the Irish Current through the Rockall Channel, it might be desirable to say a few words in general about the possibility of computing the velocities of the currents by means of the distribution of density in transverse vertical sections. In the case of currents caused by pressure-gradient and the Earth's rotation alone, and running at all depths parallel to the coast which is on the right hand side of the current,¹⁾ it is clear, if the current shall be stationary, that in a transverse vertical section of the current the component of the pressure-gradient perpendicular to the coast must at each level be exactly equal to the deflecting force due to the Earth's rotation, pressing the moving water against the coast.

If the velocities of the current decrease downwards, as they generally do in the sea, the deflecting force due to the Earth's rotation is so much greater in the upper strata than in the lower ones, as the horizontal velocities are greater, because the deflecting force is proportional to the velocity of the water. If there is lateral equilibrium, the pressure-gradient in each stratum must consequently also be proportional to the velocity of the water, in order to counterbalance the deflecting force. The consequence must be that the upper layers are so much more piled up against the coast (or depressed near the coast which means the same thing) than the lower ones, as their velocities are greater.

¹⁾ We discuss here the conditions on the northern hemisphere only.

The layers will thus be depressed on the right hand side of the current and will slope more or less towards the coast.

This fact was used by Prof. V. Walfrid Ekman in 1901 for computing for me the probable difference between the velocities at the surface and at 200 metres in a section from Norway to Bear Island across the North Cape Current [see Nansen 1901, p. 160; 1902, p. 285]. Dr. B. Helland-Hansen [1905, p. 4 et seq.] has by a modification of Bjerknes's formula developed this method of computing the velocities of currents into a very convenient form.

The method is, however, not quite adequate to the computation of the differences of velocity at different depths in currents caused directly by the wind, unless the motion be parallel to the coast at all depths in the current, which, however, is evidently very seldom the case.

Owing to the influence of the Earth's rotation, the direction of the motion in a drift-current, caused directly by the wind, will deviate to the right of the wind direction (in the northern hemisphere), and the directions of the motion of the water will differ more or less in the different strata downwards. As has been proved by Prof. V. Walfrid Ekman [1905, 1906] this will be the case to some extent even if the water of the current be stored up against a coast on its right hand side. It is, however, obvious that owing to the friction, the tangential pressure of the wind on the water-surface, and of the water-strata gliding on top of each other, will, as it were, attempt to move the water in the direction of the wind, and these tangential pressures will offer some resistance against the deviation of the current due to the Earth's rotation.

If the current be stationary, the deflecting force, due to the Earth's rotation, must consequently in this case be counterbalanced by a certain component of the tangential pressure (which will increase with the angle of deviation) in addition to the pressure-gradient due to the storing up of the deflected water against the coast. In other words, the pressure-gradient cannot in this case be as great as in the case when the deflecting force is not counteracted by any tangential pressure, and a computation of the difference of the velocities of the current at different depths must give too small values if it be based only upon the pressure-gradients, *i. e.* upon the inclination of the strata.

If the coast is on the left hand side of the current, the conditions will be much the same as above described, only that the water of the current will be sucked out from the coast instead of being piled up against

it. The strata will slope towards the right hand side of the current in the same way, and the pressure-gradient will be the same. If there is a line of resistance on the side of a current in the open sea, offered by water moving in directions different from that of the current, this line of resistance may have approximately the same effect as a coast, provided that no water from the current is allowed to flow across it, or no water flows across it into the current.

If the density of the strata of the sea increases much downwards, the directions of the motion at different levels will deviate less from each other and may even approach uniformity (cf. Ekman 1906). As there will then be less tangential pressure to counteract the deflecting force due to the Earth's rotation, the gradient of the strata will be greater, and a computation of the differences of velocity at different depths, based upon the pressure-gradient, will consequently give more accurate values.

It would carry us to far away from our subject to go into more detail in this respect here. What has been said above may be sufficient to show that a computation of the differences of velocity vertically in a current, based upon the inclination of the strata (or the difference of density) in a transverse section of the current, will not be able to give more than the lower limit of the possible values of these differences of velocity, if the current be created more or less directly by the wind; but the greater the differences that exist vertically between the densities of the strata, the nearer will the values thus computed come to the actual ones.

A simple method for computing the above values may be found in the following way: If in a transverse vertical section of an ocean current the mean density of the strata between the surface and a certain depth be lower in one part of the section, on the right hand side of the current, than in another part, on its left hand side, the sea-surface must consequently be slightly higher in the former place. If α be the slight gradient thus produced, the pressure gradient is $G \sin \alpha$, where G is the acceleration of gravitation.

Let us take two stations, 1 and 2, in such a vertical section. Station 1 is more on the right hand side of the current than station 2. Let q_1 be the mean density between the surface and the depth h at the one station and q_2 the mean density between the same levels at the other station, and $q_2 > q_1$. Let d be the distance between the two stations, v_0 the component of velocity of the current at the surface, directed perpendicularly to the direction of the section, and v_h the cor-

responding component at the depth h . If there is lateral equilibrium in the section, the deflecting force of the moving water, due to the Earth's rotation, should be equal to the pressure-gradient. We have then

$$\begin{aligned} 2(v_0 - v_h) \omega \sin \varphi &= G \sin \alpha \\ \sin \alpha &= \frac{(q_2 - q_1) \cdot h}{q_1 \cdot d} \\ v_0 - v_h &= \frac{(q_2 - q_1) \cdot h \cdot G}{q_1 \cdot d \cdot 2 \omega \sin \varphi} \end{aligned} \quad (1)$$

where ω is the angular velocity of the Earth ($= 0.0000729$), and φ the geographical latitude. If G be expressed in centimetres and h and d in metres, the value of $v_0 - v_h$ will be in centimetres per second. Instead of computing the difference of velocity between the surface and a certain depth, one can naturally also compute in the same manner the difference of velocity between any two levels in the sea. One has, however, to keep in view that the values obtained only refer to components of the motion perpendicular to the direction of the section; and moreover if the current be more or less directly created by the wind, the values obtained are only possible minimum values.

It should also be noticed that above the fact was not taken into consideration that the coefficient of thermal expansion of sea-water is much increased with pressure, and thus some inaccuracy in our computations will arise, if there are great differences between the temperatures at the same levels at the two stations. Corrections for these differences of temperature could of course be introduced, but then our method would hardly be simpler than the more accurate method of computation based upon Prof. Bjerknes's theory, for which he has arranged convenient tables [Bjerknes, 1910].

By drawing the vertical density curves of the two stations in the same manner as the curves in Fig. 17, our above method can be much simplified. With a planimeter one can then easily measure the area between the two curves, and between any two levels. By multiplying the quantity thus obtained by a constant k (which may most simply be found empirically once for ever) and dividing by $d \sin \varphi$, one obtains directly the difference between the velocities at the two levels.

If the scale of the ordinate system of the density curves be so arranged that along the ordinate 2 cm = 100 metres of depth, and along the abscissa 2 cm = 0.0001 of density (*i. d.* 0.1 of σ_t), and the area between the curves be measured in square centimetres, the constant k will be = 16.381, if d (the distance between the stations) be expressed in kilometres. If the area between the curves be a , we have then

$$v_0 - v_h = \frac{a \cdot 16.381}{d \sin \varphi} \text{ cm/sec.} \quad (2)$$

The computation may naturally be still more simplified by arranging a table giving the value of $\frac{16.381}{\sin \varphi}$ for each degree of latitude.

Let us now return to our section across the Rockall Channel, and by means of the above method we may attempt to compute the velocities of the current running northwards along the continental slope, between stations 1 and 2. Let us first consider the water-strata between the depths of 250 and 750 metres, where we have observations at both stations. The mean density of these water-strata should be about 1.027384 at Station 1, and 1.02744 at Station 2,¹⁾ or if we measure the area between the two density curves as mentioned above, we find $a = 11.2 \text{ cm}^2$. The distance between the two stations was about 38.8 kilometres. Computed by means of the equations (1) or (2) the velocity component of the northward movement of the water perpendicular to the section should then have been 5.7 cm per second greater at 250 metres than at 750 metres.

It is not probable that the water at 750 metres, was at rest between Stations 1 and 2; the gradients of the isopycnals in the section (Pls. IX and XI) rather indicate that the water below this depth was also moving northwards along the continental slope. The curves of density of the different stations (Fig. 17) also indicate that the water cannot have been at rest at 750 metres, and hardly at less than 1500 metres, because the differences of density are too great. If we assume that the density curve of Station 1 would have had a shape approaching that of Station 3 (see Fig. 17) if it could have been continued downwards over the continental slope, and moreover that the water of the deeper strata, down to 1500 metres, were flowing northwards, and that the velocity was decreasing downwards to about 0 at this level, the velocities of the northward current may then have been, at the depth of 1000 metres 9.8 cm/sec., at 750 metres 17.3 cm/sec., at 500 metres 20.9 cm/sec., at 250 metres 23.0 cm/sec., and at 100 metres below the surface 22.2 cm/sec., which is about 10.4 naut. miles, or 25 kilometres, in 24 hours. The mean northward velocity of the

¹⁾ For the computation of the latter value the observations taken at 400 metres (Station 2) at 6,30 p. m. (July 6. 1910) were used. If the observations taken at the same depth 25 minutes later (6,55 p. m.) be used, the mean density, will be higher.

whole body of water between 100 and 1500 metres should then have been about 14 cm per second, *i. e.* 12 kilometres, or 6.5 naut. miles, in 24 hours.

It has, however, to be kept in view, that the above computations are very unreliable, as there are no observations near the continental slope deeper than 750 metres, and we have to find the probable densities at lower levels by a hypothetic continuation of the curve of Station 1 in Fig. 17. Another difficulty is the fact that the two observations taken with an interval of 25 minutes at 400 metres, at Station 2 (see the Table), seem to indicate that the vertical distribution of density was not stable in that region. The first observation at 400 metres, at 6.30 p. m. (July 6, 1910) gave 8.93°C. , and 35.34‰ , hence a density of 27.42, while the observation only 25 minutes later (at 6.55 p. m.) at the same depth with the same instrument gave 8.38°C. and 35.31‰ , hence a density of 27.49 (which may be somewhat high as the salinity of 35.31‰ is possibly a few hundredths too high). Both observations were taken with the Pettersson-Nansen water-bottle and a "Nansen-thermometer", and I can see no possibility of a mistake as to depth or temperature. Two hours earlier a temperature of 9.5°C. (with 35.37‰ and $\sigma_t = 27.35$) was observed at 215 metres, and an hour earlier 8.27°C. (with 35.255‰ , and 27.46) at 600 metres. In those 25 minutes there should thus have been a change in the water at 400 metres which equalled a vertical displacement of about 160 metres, if we may judge from the apparent decrease of temperature with the depth, according to the serial observations. Our computation of the mean density of the strata between 250 and 750 or 1500 metres will therefore be somewhat unreliable. If we use the density obtained by the last observation at 400 metres at Station 2, the mean density of the strata will be higher, and the computation will give a greater velocity at 250 metres.

Let us, however, assume that the values of velocity found above are fairly correct, and that the water between 100 metres and the surface was also flowing northwards between Station 2 and the continental slope, but with velocities decreasing upwards. We might then estimate the mean northward velocity of the whole body of water between the surface and 1500 metres to be somewhere about 12 kilometres in 24 hours. The distance between Stations 1 and 2 was 38.8 kilometres.

Between these stations there should accordingly have been carried about 698 cubic kilometres of water every 24 hours, *i. e.* about 29 cubic

kilometres hourly, or 8 million cubic metres of water per second.¹⁾ But a calculation such as this is naturally very uncertain, being based upon an altogether inadequate number of observations.

It was pointed out above that in the case of currents caused more or less directly by the wind, the values of velocity found by the above method could only be considered as minimum values. It seems hardly possible, however, that the current through our section across the Rockall Channel has to any appreciable extent been caused directly by the wind, for in that case it could not have been limited to such a narrow belt along the continental slope, but would rather have been extended in breadth over the whole area affected.

The descent of the isopycnals at Stations 3 and 4 may indicate that there has been some kind of vortex-movement in this central part of the channel. Provided that there has been lateral approximate equilibrium in the section, the gradients of the isopycnals of 27.40—27.71 might indicate that between Station 2 and Station 3 the water was moving in some southerly direction, at least between 100 and 1000 metres, and the velocities of the movement were decreasing with the depth from a maximum at about 200 metres. Near the surface there is a rise of the isopycnals near Station 3, which may indicate a decrease of the velocity of this same movement, from the level of the maximum upwards towards the surface.

The distance between stations 2 and 3 is about 76 kilometres. Let us assume that the density curves of stations 2 and 3 in Fig. 17 are fairly correct, although there are no observations at the depths between 1000 and 1500 metres. Provided that the water was approximately at rest at 1500 metres, we then find by our above method the following velocities of the southward movement between these two stations, along components directed perpendicularly to the section: at 100 metres below the surface 13.7 cm/sec., at 250 metres 13.6 cm/sec., at 500 metres 12.9 cm/sec., at 750 metres 11.2 cm/sec., and at 1000 metres 6.0 cm/sec.

Between Station 4 and Station 5 the water may again have moved in a northerly direction. As the area between the density curves

¹⁾ Dr. B. Helland-Hansen [1907, p. 9] computed the volume of water carried by the current through the Faeroe-Shetland Channel in August 1902, to be about 4 million cubic metres per second. But the velocity of the current was then supposed to decrease downwards to 0 at about 600 or 700 metres. The observations of May and June 1904, gave for the same current through that channel a volume of 4.5 million cubic metres per second [see Helland-Hansen and Nansen, 1909, p. 169].

of stations 2 and 3 is very nearly the same as that between the curves of stations 3 and 5 we may conclude that on the whole very nearly the same volume of water is carried northwards between stations 3 and 5 per second, as is carried southwards between stations 2 and 3.

The above rough computation presupposes that there was lateral equilibrium in the section, which, however, may be very doubtful, and the values obtained are therefore unreliable; but they may none the less give some idea of the nature of the motions.

It appears consequently to be probable that there has been some vortex movement in this sea. In the middle of the channel the vortex-movement has had an anticyclonic direction, by which in the central part of the vortex, at Stations 3 and 4, the water with a nearly uniform density of about 27.40, has been pressed down to great depths approaching 1000 metres.

It is obvious that in a sea, where the differences of density vertically are so small, even slow movements may be able to stir great water-masses, and the effects will be extended to much greater depths than where the densities of the strata differ more. In such a sea it is even possible that great vertical vortex movements (with horizontal axes) may occur. It is possible that the occurrence, at Station 3, of water of 9.17°C . and 35.34‰ at 800 metres, lower than water of 8.70°C . and 35.27‰ at 600 metres, if these observations be actually correct, may be explained by such vertical vortex-movements. It should be noticed that there was an interval of two hours between the two observations (see the Table). At 400 metres (Station 3) 9.18°C . and 35.35‰ were observed at 2.39 a. m. (July 7, 1910). This was apparently the same kind of water as the observations gave two hours and a half later (at 5.05 a. m.) at 800 metres.

It may seem difficult to believe that there is not some error in these observations, *e.g.* by the reversing water-bottle used at 800 metres having been reversed at some higher level, but as was pointed out above (p. 12), there is apparently a certain system in all observations at Stations 3 and 4 from 400—1000 metres. And the two observations, mentioned above (p. 51), at 400 metres at Station 2, taken with an interval of 25 minutes only, might indicate great vertical movements in this sea at that period, or great differences at short distances horizontally.

A great horizontal vortex-movement in the Rockall Channel may also be indicated by some of the charts for different depths, *e.g.* for 400 and 500 metres (Pls. VII and VIII). The chart for 100 metres

(Pl. IV) might indicate that the water of 35.41 and 35.42‰ at about 100 metres at Station 4 and west of it (see Section I, Pl. X) has been carried so far westwards by an anticyclonic vortex-movement.

Disregarding these possible vortex-movements and other details, the general result of our study of the vertical distribution of density in Section I, may be that the northward flow of the water of the Irish Current through the Rockall Channel, — which also forms the Atlantic Current through the Faeroe Shetland Channel — is chiefly limited to a narrow strip along the continental slope on the eastern (right) side of the channel. The velocities of the current may have their maximum at about 200 or 250 metres, and are decreasing from that level downwards as well as upwards. The surface layers may probably be carried along with the underlying water-strata, but their movements are much influenced by the changing winds, etc.

The sections, mentioned before, north and south of the Frithjof Section, give similar representations of the vertical distribution of density, which is on the whole increasing from the south, from the southern section of the Fram (Fig. 4), towards the north, to the Scottish Section D (Fig. 10), the northern section of the Fram (Fig. 11), and the Danish Section F (Fig. 12), as was pointed out above (see p. 40, and Fig. 13).

In the southern section of the Fram (Fig. 4) the isopycnal of 27.30 has a somewhat similar eastward inclination, towards the right hand side of the current (west of the Porcupine Bank as well as east of it), as the isopycnal of 27.40 in the Frithjof Section. The rise of the isopycnal over the banks is evidently due to the winter cooling of the bank waters, as mentioned before. The isopycnal of 27.40 in Amundsen's Section (Fig. 4) lies much lower, but is evidently sloping eastwards. The isopycnals of values lower than 27.20, near the surface above a depth of 100 metres, run more or less horizontally, rising slightly over the banks.

The Porcupine Section of 1869, and the Danish Section H, of May 1908, across the Rockall Channel, give hardly any indications of a northward movement of the waters. In the Porcupine Section (Fig. 5) the isotherms (and consequently also the isopycnals) do not descend appreciably deeper on the eastern side of the channel than on its western side. It seems, however, probable that this would have been somewhat different if there had been more stations, with a greater number of observations, near the eastern continental shelf.

In the Danish Section H (Fig. 7), north of the Frithjof Section, the densities at the Station Da C, in the middle of the channel, are practically the same as those at the same levels at Station Da D, near the Rockall Bank, and the isopycnals are nearly horizontal between the two stations. Hence we may conclude, that there has probably been no northward transport of water of importance through this part of the channel. As in the Frithjof Section, the northward flow of water must therefore have occurred nearer the continental slope on the eastern side of the channel; where, however, we have no observations.

All three sections, the Porcupine Section, the Frithjof Section, and the Danish Section H, consequently indicate that the current through the Rockall Channel must on the whole be slow and that the northward flow of water is chiefly limited to a comparatively narrow belt along the continental slope on the eastern side of the channel, *i. e.* on the right hand side of the current.

This is probably also the case in the Danish Section F (Fig. 12), where the isopycnal of 27.50 has taken the place of the isopycnal of 27.40 in the Frithjof Section.

The steep inclination of the isopycnal eastwards from the Faroe Bank is evidently to some extent due to the cooling of the water over the bank during the preceding winter, and the heavier bank-water was probably still sinking down along the slope. The isopycnals of 27.40 and 27.30 are here near the surface, above a depth of 50 metres. If we assume that between Stations 52 and 53, separated by a distance of 109 kilometres (59 naut. miles), the vertical distribution of density was approximately as given in Fig. 12, and that the water at 1100 metres was practically at rest, we find that the velocity of the north-eastward motion of the water (*i. e.* perpendicularly to the section) should be about 3.5 cm/sec. at the surface, 2.6 cm/sec. at 250 metres, 2.4 cm/sec. at 500 metres, 1.6 cm/sec. at 800 metres, and 1.0 cm/sec. at 900 metres. The mean velocity of the whole body of water between the surface and 1100 metres would then be about 2 cm. per second, or 1.7 kilometres (0.9 naut. miles) in 24 hours. Between Stations 52 and 53 about 204 cubic kilometres of water should thus be carried north-eastwards in 24 hours, or about 2.4 million cubic metres per second. The above computations are of course very unreliable as they are based upon a much too inadequate observation material. The values obtained are evidently too small. It is, however possible that some water may also be carried north-eastwards west of Station 52.

The high densities of the surface layers of this section (Fig. 12) as compared with those of the Scottish Section D (Fig. 10), the Frithjof Section, and also those of Amundsen's northern section (Fig. 11) are chiefly due to the much earlier date of the observations, they being taken in the last days of May, instead of in August and the beginning of July, when the sun had heated the surface layers a great deal more.

Owing to the oblique direction of Amundsen's northern section (Fig. 11) we cannot form any very definite conclusions from the shape of its isopycnals as to the velocities of the current. The vertical distribution of density is, however, similar to that of the other sections. The isopycnal of 27.40 has an intermediate position at about 200 metres, rising to 100 metres in the north-eastern part of the section which crosses the Danish Section F (Fig. 12). Owing to the earlier season of the latter section this isopycnal has there a still higher position.

In the Danish Section K (Fig. 14) north-eastwards from the Rockall Bank, the isopycnals of 27.40 and 27.30 have very much the same position as in Amundsen's section (Fig. 11); they are very nearly in the same depth over the bank (cf. also the Danish Section H, Fig. 7, and the Frithjof Section, Fig. 6), but north-east of the bank the isopycnal of 27.40 descends somewhat deeper in Fig. 14 than in Fig. 11.

The conclusion we arrive at from our examination of the different sections of the Rockall Channel is consequently that, Atlantic water with comparatively high salinities keeps flowing slowly north-eastwards along the continental slope off the west coast of Ireland and Scotland.

VI. The Deep-Water of the Rockall Channel, partly from the Mediterranean Sea.

At a depth of 1500 metres, at Station 2a, near the continental slope on the Irish side of the channel, a temperature of 4.08°C . and a salinity of 34.97‰ ¹⁾ were observed. This water thus approaches

¹⁾ By a titration of this sample, made in August, 1911, Mr. I. Gröndahl found a salinity of 34.90‰ . As the value seemed rather low, Dr. Helland-Hansen kindly made two titrations of the sample in January 1912, and found 34.97 and 34.99‰ . He writes January 8, 1912, from Bergen that there is little water left in the bottle, and some evaporation may have occurred by the repeated opening of the bottle, but it cannot be much. On May 17th, 1912, I examined the sample with the interferometer and found a salinity of 35.005‰ . There was then

the type of the regular deep-water of the North Atlantic, which, near the sea-bottom, has temperatures approaching 2°C . and salinities about 34.90 or 34.92 ‰ [cf. Helland-Hansen 1911, 1912; Brennecke 1911; Nansen 1912]. We may therefore assume that the Atlantic deep-water also occurs in the Rockall Channel, but it has there somewhat higher temperatures and salinities, owing to admixture with warmer and saltier water. Near the continental slope, at Station 2a, this mixed water has been lifted to a higher level (1500 metres) than in the middle of the channel, at Stations 3 and 4.

The rising of the cold deep-water along the continental slope to much higher levels than in the central region of the sea basin, is a feature which has been regularly observed off the west coast of Norway.

The deep-water with salinities between 34.90 and 35.00 ‰ and temperatures about or somewhat lower than 4°C . may possibly form a continuous layer across the Rockall Channel at depths of about 1600 and 1700 metres or even more (cf. Figs. 15 and 16, and Pl. IX).

It is, however, a most remarkable fact that at greater depths, at 2000 and 1900 metres, near the bottom at Stations 4 and 5 (see Pl. IX) much higher salinities and also higher temperatures were found. Six titrations of the water-sample from 2000 metres at Station 4, gave a mean value of 35.38 ‰.¹⁾ Four titrations, and several determinations with the interferometer, of the sample from 1900 metres at Station 5 gave 35.31 ‰.²⁾ The temperature was at 2000 metres 5.41°C . and at 1900 metres 4.83°C . I can find no possibility of any mistakes in these cases. If by some unaccountable accident the water-bottle had been reversed in both cases at some levels between 200 and 600 metres, while being hauled up, this might account for the

only a small quantity of water in the bottle. Helland-Hansen's determinations are very accurate, as are my own, but, considering the probability of a slight evaporation, perhaps even before Helland-Hansen's first titration, I have accepted 34.97 ‰ as the most probable value.

¹⁾ The salinities found by the titrations were the following: December 1910 (by I. Gröndahl) 35.35 ‰, March 1911 (by Helland-Hansen, but titration hurriedly made) 35.34 ‰, Aug. 1911 (by I. Gröndahl) 35.38 and 35.43 ‰, January 1912 (by Helland-Hansen) 35.38 and 35.40 ‰. There was too little water left in the bottle to give accurate results by an examination with the interferometer.

²⁾ The sample was kept in a bottle holding 500 cc. The titrations were made by Helland-Hansen in January 1912, and gave: 35.30, 35.32, 35.29, and 35.33. In May 1912 I examined the sample with the interferometer and found a salinity of 35.31 ‰.

high salinities, but then the observed temperatures would be much too low, for they ought then to have been above 8° C. at least, even if it be assumed that the water-bottle was hauled up so quickly that the thermometer did not get time to acquire the temperature of the stratum before it was reversed. There is no possibility of the water-bottle having leaked, the stop-cocks were perfectly tight during the whole cruise, and no drop of water could possibly get in or out of the closed bottle.

The water with these high salinities at 1900 and 2000 metres, underlying water-strata with a much lower salinity and lower temperature, must apparently have been intermixed with water from the Mediterranean Sea, carried into the Atlantic by the undercurrent through the Straits of Gibraltar. The comparatively warm but heavy water of this outflowing undercurrent, forming an intermediate layer in the eastern Atlantic near the Spanish Bay was first discovered by Dr. W. B. Carpenter [1871; 1872; 1874; Carpenter and Jeffreys 1871] during the Porcupine-Expedition in 1870. In spite of its comparatively high temperature (above 10 or 11° C.) this water has a high density, owing to its very high salinity, above 36‰ or even partly above 36.5‰ ; it, therefore, sinks down along the continental slope outside the strait until it reaches strata with similar densities, and forms there, between 800 and 1400 metres, an intermediate layer, with a secondary maximum of salinity. This intermediate layer extends over great areas in the eastern regions of the North Atlantic, and has been traced for great distances along the continental slope¹⁾. The water spreads only a short distance towards the south-west along the African coast, more widely westwards towards the Azores [cf. Helland-Hansen, 1912, p. 296], but its widest extension is northwards along the continental slope, as might be expected owing to the deflecting effect of the Earth's rotation. During the slow northward movement the high salinity of the water of this intermediate stratum will be gradually reduced by admixture with overlying and underlying water. By admixture especially with the latter, and to some extent by contact with the colder water, the temperature will also be lowered, and the density will be

¹⁾ Cf. Buchanan, 1885, p. 966; 1888, p. 194; Buchan, 1895; Schott, 1902, p. 185; Thoulet (Prince of Monaco), 1902, 1905; J. N. Nielsen, 1907, p. 21; W. Brennecke, 1909, p. 71, Pl. 20; Schmidt, Nielsen, and Jacobsen, 1910, p. 248; Johan Hjort, 1911; Helland-Hansen, 1911; 1912, p. 292 *et seq.* See also Krümmel, 1907, p. 338 etc., 1911, p. 616 *et seq.*

somewhat increased¹). Some part of the water will thus gradually sink to lower levels.

This is obviously the origin of the water with the remarkably high salinities at 1900 and 2000 metres in the Rockall Channel.

During the Prince of Monaco's cruise in the Princess Alice in 1903, three vertical series of temperatures and water samples were taken in the Bay of Biscay. The temperatures observed are very interesting, and the salinities observed, if they were correct, might seem to prove that even the deep-water, at depths of 4000 and 4500 metres, in the Bay of Biscay, is intermixed with water from the Mediterranean Sea. But the values of specific gravity and salinity found, are unfortunately not trustworthy.

According to the values given by Prof. Thoulet [1905, p. 86 and 88] the following observations were made²):

Depth in Metres	Stat. 1504		Stat. 1556		Stat. 1563	
	13. VIII. 1903		7. IX. 1903		10. IX. 1903	
	44° 34' N., 4° 39' W.		45° 27' N., 6° 05' W.		44° 43' N., 6° 24' W.	
	t° c.	S‰	t° c.	S‰	t° c.	S‰
500	10.7	35.65	11.4	35.65	11.2	35.56
1000	9.8	.59	9.9	.55	10.0	.46
1500	6.3	.55	6.5	.59	6.6	.39
2000			4.3	.55	3.2	.30
2500	3.2	.53	3.0	.52	3.9	.21
3000	2.8	.43	3.2	.45		
3500	2.7	.57	1.8	.34		
4000			2.5	.34		
4500					3.9	.12

These values of salinity for the deep strata, at depths greater than 2000 metres, are more or less improbable. *E. g.* water with temperatures of 2.8° C. and 3.2° C. cannot possibly have salinities of 35.43‰ and 35.45‰, as observed at 3000 metres. Let us assume that the water has been formed by an intermixture of the Mediterranean water, carried through the Straits of Gibraltar, with the regular

¹) As was mentioned above (p. 17), by intermixture of waters with approximately the same density but with different salinities, the mixed water will have a higher density than any of the original waters. In the above case the Mediterranean water will also be cooled by contact with surrounding waters, and the density will be still further increased.

²) The salinities are computed by Knudsen's Tables from Thoulet's specific gravities ($S \frac{0}{4}$). His values of Halogen give much higher values of salinity, and do not at all agree with his specific gravities.

deep-water of the North Atlantic. Let us moreover assume that the values of the former water be 10.8°C . and 36.15‰ [cf. Helland-Hansen, 1912, p. 294], and those of the latter 2.4°C . and 34.92‰ . A simple computation will show that an intermixture of these two waters giving a salinity of 35.44‰ , should have a temperature of about 5.9°C ., provided that the temperature be not changed by contact with other water. There is, however, no conceivable agency which could lower the temperature of the water to about 3.0°C . Even if it be assumed that the water at 3000 metres in the Bay of Biscay was produced by a direct intermixture of the deep-water of the North Atlantic (of 2.4°C . and 34.92‰) with the Mediterranean water of 12.87°C . and 38.39‰ in the Straits of Gibraltar [cf. Helland-Hansen, 1912, p. 293], which would be the most favourable conditions imaginable, for producing cold water with a high salinity, — the intermixed water with a salinity of 35.44‰ would still have a temperature of about 3.9°C .

Though these determinations of the deep-water of the Bay of Biscay might appear to support my view as to the origin of the deep-water of the Rockall Channel, they have unfortunately to be given up, as the values of salinity are obviously much too high.

Some very important vertical series of temperature and salinity were, however, taken in the northern region of the Bay of Biscay by the Danes in 1905 and 1906, and on the German expedition with the Planet in January 1906 (see Fig. 18). Some of these observations are given in the following table (see p. 61).

At the Planet Stations 2, off Portugal (see P 2 in Figs. 18 and 19), the water at 800 metres (10.7°C ., 35.79‰) was very similar to water found at the same level in the Spanish Bay where 10.4°C . and 35.73‰ were observed at Station 3 of the Planet Expedition [Brennecke, 1909, p. 51], and about 10.7°C . and 35.90‰ at Stations 29 and 30 (see Fig. 18, MH 30 and Fig. 19, MH 30) of the Murray Hjort Expedition in 1910 [cf. Helland-Hansen 1912, p. 294]. At the Danish Station Da I in $46^{\circ} 30' \text{N}$ and $7^{\circ} 0' \text{W}$ (see Fig. 18, Da I) the same kind of water occurs between 800 and 1200 or even 1500 metres, and it can be traced towards the north-west as far as the Danish Station Da III in $50^{\circ} 16' \text{N}$ and $12^{\circ} 55' \text{W}$ (Fig. 18, Da III), with comparatively high salinities at between 800 and 1200 metres. The many vertical series of observations taken in the same region south-west of Ireland by the Irish Oceanic Survey, in 1905–1910 [cf. Bull. Trimestriel, Copenhagen] also perhaps exhibit traces of this kind of

Depth in Metres	P. 2 28. I. 1906 41°19' N, 11°31' W		Da I 11. IX. 1906 46°30' N, 7°00' W		P. 1 26. I. 1906 46°52' N, 7°4' W		Da II 7. VI. 1906 48°4' N, 12°40' W		Da III 5. VI. 1906 50°16' N, 12°55' W		Da IV 23. VI. 1906 55°45' N, 9°35' W		Frithjof ³⁾ 6. VII. 1910 55°50' N, 9°45' W	
	t° C.	S°/∞	t° C.	S°/∞	t° C.	S°/∞	t° C.	S°/∞	t° C.	S°/∞	t° C.	S°/∞	t° C.	S°/∞
0	13.4	35.84	18.8	35.64	11.6	35.49	13.3	35.61	12.0	35.50	12.1	35.34	13.1	35.29
100	13.0	35.70	11.7	35.61			11.2	35.53	10.6	35.46	9.4	35.35	9.7	35.36
200	11.8	35.61	11.1	35.59									9.5	35.37
400	11.0	35.52	10.8	35.58			10.5	35.49	10.0	35.44	8.9	35.35	9.0	35.34
600	10.6	35.57	10.6	35.58	10.4	35.52			9.6	55.39			8.7	35.30
800	10.7	35.79	10.4	35.70	10.0	35.70	9.5	35.52	8.7	35.39	8.3	35.29	8.2	35.28
1000			9.7	35.77	9.4	35.66	9.0	35.62	8.1	35.44	7.9	35.29	7.6 ³⁾	35.20 ³⁾
1200			8.6	35.64			7.6	35.47	6.7	35.31	5.8	35.16		
1500			6.5	35.39	6.5	35.35	5.6	35.22	4.7	35.08	4.3	35.01	4.4 ³⁾	35.00 ³⁾
2000			4.6	35.08			3.6	34.97	3.8?	34.97	4.0 ¹⁾	34.99 ¹⁾	5.4 ⁴⁾	35.38 ⁴⁾
3000						35.08	2.7	34.94						
3500			2.6	34.97										
4610														

¹⁾ These observations are from the Danish station on 22nd June 1906, in 55° 5' N., and 12° 20' W. The temperature is stated to be inaccurate, probably somewhat too high.

²⁾ For depths between surface and 800 metres the mean values are taken of the observations made at Stations 1 and 2.

³⁾ Mean values of observations from Stations 2a, 3, and 4.

⁴⁾ Observations from Station 4.

water; but as a rule these series do not descend deeper than about 1000 metres, and the values obtained seem often somewhat puzzling.

Fig. 18. Bathymetrical Chart of the North Atlantic. Isobaths are drawn for depths of 200, 1000, 2000, 3000, 4000, and 500 metres. Depths greater than 3000 metres are denoted by three different degrees of shading, 3000—4000 metres, 4000—5000 metres, and more than 5000 metres.

At the Danish Station IV in $55^{\circ} 45' N$ and $9^{\circ} 35' W$ and at the Frithjof stations, there are no distinct traces of this intermediate layer of saline water, though the comparatively high salinities of 35.29‰ , at 1000 metres at the Danish station, and 35.23‰ , at the Frithjof Sta-

tion 4, may be due to remnants of the same water. But the water of 35.38 ‰ at 2000 metres at the Frithjof Station 4 (and the similar water at 1900 metres at Station 5) is evidently the same

Fig. 19. Section along the line drawn in Fig. 18 from Stat. 30 of the Murray Hjort Expedition, in $34^{\circ}38'N$ and $8^{\circ}22'W$ in the Spanish Bay, to the Frithjof Station 46 in the Faeroe-Shetland Channel, showing the vertical distribution of Temperature and Salinity in the deep sea along the west coast of Europe. Horizontal Scale 1:36,000,000; Vertical Scale 1:30,000.

kind of water which has there sunk to lower levels. There are no indications of similar water at that depth at the stations farther south. At three stations between $47^{\circ}20'$ and $50^{\circ}16'N$ and between $12^{\circ}23'$ and $12^{\circ}55'W$ the Danes observed about $3.6^{\circ}C$. and 34.97‰ at 2000 metres;

at their most southern station in the above Table they found 4.6° C. and 35.08‰ at that depth, and at a station in $55^{\circ}5'N$ and $12^{\circ}20'W$ about 4.0° C. (?) and 34.99‰ .

Fig. 19 represents a section along the continental slope from the Spanish Bay to the Faeroe-Shetland Channel along the line drawn in Fig. 18. The section passes through Station 30 (MH 30) of the Murray Hjort Expedition (in the Spanish Bay), Station 2 of the Planet Expedition (P. 2), the Danish Station Da I of 11th Sept. 1906, in the Bay of Biscay (Da I), two Danish Stations (Da II, Da III) of June 7th and 5th,

Fig. 20. Vertical Curves of Density (σ_t) at the Frithjof Station 2, the Danish Station I and III (Da I and Da III see Fig. 18), and the Planet Stations 2 and 6 (P 2 and P 6, see Fig. 18).

1906, southwest of Ireland, Amundsen's Station 12 (A 12) of the Fram Expedition June 27th, 1910¹⁾, the Danish Station (Da IV) of 22nd June, 1906, in the Rockall Channel, Stations 1 and 2 (means) of the Frithjof Expedition (F 2)²⁾, the two Scottish Stations (Sc I) of 22nd

¹⁾ The observations at 1000 and 2000 metres are from Amundsen's Station 13.

²⁾ The values of t° C. and $S\text{‰}$ between the surface and 800 metres, are the mean values of the observations at Stations 1 and 2, the values at 1000 and 1500 metres are the mean values of the observations at Stations 2a, 3, and 4, at 1900 metres from Station 5, and at 2000 metres from Station 4.

and 23rd August 1910 (cf. Fig. 10)¹⁾, Amundsen's Stations 21 and 22 (A 22) of July 6th, 1910²⁾. Hence the section is continued across the Wyville Thomson Ridge along the Faeroe-Shetland Channel through the Scottish Station Sc 13 A of August 1910 (see Fig. 50) and the Frithjof Station 46 (see Pl. XVI).

This longitudinal section demonstrates the northward extension along the continental slope, of the intermediate layer of Mediterranean water.

It may seem difficult to understand how the salt water at 1900 and 2000 metres at our Stations 4 and 5 has been able to sink gradually from above, down to these levels, through less saline water; but at the southernmost Danish Station in the above Table (and in Fig. 19) and at the Planet Station 1 (in the above Table) we find water with a similar salinity (35.39 and 35.35‰) and a somewhat higher temperature (6.5° C.) at 1500 metres. It does not then seem inconceivable that water of 5.4° C. and 35.38‰ may also be formed. If we presume that this deep-water was simply formed by an intermixture of Mediterranean water of 10.8° C.³⁾ and 36.15‰³⁾ with the regular North Atlantic deep-water of 2.4° C. and 34.92‰, it ought to have a salinity of 35.36‰ if the temperature be 5.4° C., and a salinity of 35.28‰ with a temperature of 4.83° C.

This agrees remarkably well with the values observed at 2000 and 1900 metres at our Stations 4 and 5.

The discovery that the intermediate layer of mixed Mediterranean water extended so far north as Ireland was first made by the Danes in 1905 [Nielsen, 1907]. During the Danish cruise with the Thor, in June 1905, a secondary maximum of salinity (of 35.64 and 35.55‰) was found at a depth of 1000 metres on the continental slope south and southwest of Ireland, and Mr. J. N. Nielsen [1907, p. 5, 20 *et seq*] drew the correct inference that this maximum must be due to admixture with the water from the Mediterranean Sea. But Mr. Nielsen also

¹⁾ Between the surface and 400 metres the values are the means of the observations at both stations, the values at greater depths are from the station of August 23rd.

²⁾ The values between the surface and 500 metres are the means of the observations at Amundsen's Stations 21 and 22 (see Fig. 11). The observations at 1000 and 1155 metres are from the Danish Station 52 of May 30th, 1905 (see Fig. 12) [cf. Nielsen, 1907, p. 4].

³⁾ These values are the means of Helland-Hansen's values for 1100 metres at Stations 29 and 30 [cf. 1912, p. 294].

thinks "it is highly probable that the great bulk of warm and salt water" found in the Rockall Channel, "is due to nothing else but" the northward extension of the same kind of water. Mr. Nielsen does not state clearly what he means by "the great bulk of warm and salt water" in the Rockall Channel. If he means the water at depths greater than, say, 800 or 1000 metres, he may to some extent be right; but if he also means the warmest and saltiest water in the Rockall Channel, which is between the surface and 800 metres, he is evidently not right. As will be mentioned presently, the top-layers of water in the Rockall Channel, come to a great extent from the south; but as, *e. g.* on the north side of the Bay of Biscay, they are separated from the intermediate layer (with a maximum of salinity at about 1000 metres) by intervening strata with lower salinities, it is hardly conceivable that the high salinities of the top-layers can to any appreciable degree be due to intermixture with that intermediate layer.

It is strange that no Danish observations either in 1905, 1906 or 1908 give indications of a deep-water in the Rockall Channel with so high a salinity that it might be formed by admixture with water from the Mediterranean Sea, though several observations were taken at depths of 1900 and 2000 metres, — nor is this the case with the Scottish deep-sea observations in the northern part of the Rockall Channel in 1910, or the observations of the Murray Hjort Expedition in 1910. These facts seem to prove that the whole of the deep part of the channel cannot be filled with the mixed Mediterranean water, which may possibly form a very thin layer, or may have a somewhat local distribution.

Professor Otto Pettersson [1900, p. 65] thought that the observations of the Danish Ingolf Expedition in 1895—1896, proved that the deep-water of the North Atlantic has a higher temperature in the eastern basin, south of Iceland and south-west of the Faeroe-Iceland Ridge, than in the western basin south of the Denmark Strait and Greenland, and he endeavours to explain this as being due to an admixture of the water from the Mediterranean Sea in the eastern basin. I consider it, however, to be very doubtful whether the deep-water of the North Atlantic south of Iceland, is to any appreciable degree intermixed with the water from the Mediterranean. The possibility is not excluded, but I know no observation hitherto which may justify such a conclusion; while, on the contrary, several observations point in the opposite direction.

VII. The Origin of the Irish Current, the so-called "Gulf Stream", through the Rockall Channel.

It has been a generally accepted axiom that the warm Atlantic current, the Irish Current, flowing towards the north-east in the sea west of the British Isles, is a continuation of the "Gulf Stream", which is supposed to be a drift current flowing across the North Atlantic, from the American side towards Europe, and being originally formed by the waters of the Florida Current, through the Florida Strait, and the West Indian Current, running north from the sea east of the West Indies. This view is chiefly based upon a great number of observations of the surface drift across the North Atlantic. The surface drift — *e. g.* observed by drift bottles, by the deviating drift of ships, etc. — may be very valuable for a study of the circulation of the surface waters of the sea, and the above view may therefore be more or less correct for the drift currents on the surface across the North Atlantic. But the movements of the surface waters are greatly dependent on the changing winds, and the prevailing direction of the latter will therefore have a determining effect upon the direction of the surface driftcurrents. It seems, however, to be a somewhat doubtful method to base conclusions as to the currents of the strata below the surface, merely upon observations on the surface. I consider it probable that the views thus attained, may in many cases be more or less erroneous, and I think it is so in the case of the "Gulf Stream" west of Ireland, which according to my view, is to a very great extent a current coming from the south, along the continental slope west of Europe.

It has been already pointed out that the gradients of the isopycnals in the southern section of the Fram (Fig. 4) indicate that the water of the upper 500 metres, and probably much deeper, flows northwards, along the continental slope west of southern Ireland.

During the Murray Hjort Expedition in the Michael Sars in 1910, a section with 14 research stations was taken across the North Atlantic from Newfoundland to the continental slope south-west of Ireland. The observations are not yet published in detail, but in Murray's and Hjorts book [1912, p. 115; see also Hjort 1911] Dr. B. Helland-Hansen has given a most interesting diagram, showing the vertical distribution of temperature and salinity in the section (Fig. 21).

In the eastern part of the section, the isotherms of 14° and 12°C .

run fairly horizontally at about 40–60 metres, rising slightly eastwards towards Ireland. But the isotherm of 10° rises to about 350 metres at Station 91 (July 22nd, 1910) in $47^{\circ}32'N$, and $16^{\circ}38'W$, and thence it slopes towards the continental slope southwest of Ireland, where it is at about 540 metres. The isotherms of 8° , 6° , and $4^{\circ}C$, which are drawn in the diagram (see Fig. 21), have similar slopes eastwards, but the gradient decreases with increasing depth, and the isotherm of $4^{\circ}C$, at about 1600 metres, has only a very slight gradient.

The isohaline of 35.00‰ is also drawn in the diagram and has an eastward slope, similar to those of the isotherms. The densities are

Fig. 21. Section across the North Atlantic from the Newfoundland Bank to Ireland, of the Murray Hjort Expedition, July 1910. The horizontal shading denotes salinity between 35.0 and 35.5‰ , the cross shading salinity above 35.5‰ . The vertical scale is about 1200 times exaggerated in proportion to the horizontal scale.

not given, but we know that the isopycnals follow on the whole very closely the shapes of the isotherms; consequently, in the upper 100 metres, they lie nearly horizontally, rising slightly eastwards, but in the deeper strata, they slope eastwards, towards the continental slope.

Thus the vertical distribution of density is very similar to what was found in the sections farther north, in the Rockall Channel west of Ireland and Scotland, and it is justifiable to infer that the water between the surface-layers and 1600 metres or deeper, was flowing slowly northwards through the section, along the continental slope south-west of Ireland, with velocities which had perhaps a maximum at a depth of about 200 or 300 metres, and which were decreasing downwards to.

below 1600 metres. The velocities of the surface layers were possibly decreasing slightly from 200 metres upwards, but the movements of the waters near the surface are greatly dependent on the local winds etc.

It has to be kept in view that the distances between the stations are comparatively great, and if there had been more stations, there would probably have been more undulations in the isotherms near the slope.

The current which we see flowing northwards along the continental slope through this section is obviously the same current along the slope, which we see in the sections across the Rockall Channel.

There are no vertical sections of the North Atlantic farther south, which can give detailed information of the vertical and horizontal distribution of density near the continental slope off France, Spain, and Portugal.

From what little we know I think, however, it may be concluded with tolerable certainty, that along the continental slope from Portugal to the English Channel, the strata of equal density below the top-layers, incline eastwards, and the water of the strata down to depths of 1000 metres, and more, is consequently flowing northwards along the slope.

In his account of the oceanography of the Valdivia Expedition [1902, Pl. XXVIII] Prof. Gerhard Schott has constructed a section, demonstrating the vertical distribution of temperature, across the Atlantic from Cape Hatteras towards the Straits of Gibraltar, in about 35° N. Lat. (see Fig. 22).

This section is based upon the observations of all earlier expeditions. In the eastern part of the section, between 20° W. Long. (east of the Azores), and the coast of Morocco, the isotherms incline eastwards at all levels below 100 or 150 metres, while above that level they rise towards the African coast (see Fig. 22).

The conditions are consequently very much the same as west of Ireland. Although the water between 800 and 1400 metres has very high salinities in the Spanish Bay, owing to the Mediterranean water carried by the under-current out through the Straits of Gibraltar, we may assume that on the whole the isopycnals have very much the same inclinations as the isotherms. Hence we may infer that, according to the section constructed by Schott, the water strata, below the depth of 100 or 150 metres, have a slow northward motion along the continental slope, west of the Spanish Bay. The surface strata,

above 100 metres may possibly have a southward motion, as shown by the isotherms of the section. This southward surface current the Canary Current may be the cause of the cold water (the cold "Auftriebwasser" of the German oceanographers) along the coast of Morocco,

Fig. 22. Section across the North Atlantic in about 35°N. Lat., and eastwards from 40° W. Long., showing the vertical distribution of Temperature. Constructed by G. Schott [1902, Pl. XXVIII]. Vertical scale about 1500 times exaggerated in proportion to horizontal scale.

the colder and heavier underlying water being lifted to higher levels on the left-hand side of a current in the northern hemisphere [cf. V. W. Ekman, 1906, p. 30; Helland-Hansen, 1911, p. 450; Krümmel, 1911, p. 592].

During the Challenger Expedition of 1873 a vertical section, with

a great number of serial soundings, was taken across the North Atlantic from the Bermudas to Madeira.

The isotherms of the eastern part of this section, between the Azores and Madeira, lie very nearly horizontally in the upper layers down to about 150 metres (see Fig. 23, taken from W. Thomson, [1877, vol. II, Pl. XVI]), but at depths between 100 and 800 fathoms, *i. e.* between 180 and 1500 metres, the isotherms slope very distinctly eastwards towards Madeira. The isopycnals would evidently have similar inclinations (if they could be drawn), indicating that the water of these strata was probably flowing slowly northwards. This conclusion is strikingly like those we arrived at farther north.

During the Murray Hjord Expedition of 1910, a vertical section with serial soundings was taken westwards from the Canary Islands. In the diagram of the section given by Helland-Hansen [1912, p. 84], the isohalines and isotherms between the surface and 1500 metres, lie fairly horizontally, indicating that there cannot have been much horizontal motion northward or southward through this section. As there is a slight inclination, especially of the isotherms, from the most eastern station, Station 44, westward to Station 49 and 50, this might indicate a slow southward movement of the water in

Fig. 23. Section of the Challenger Expedition, of July 1873, from the Azores to Madeira, showing the vertical distribution of Temperature (Centigrade). [W. C. Thomson 1877, II, Pl. XVI]. Vertical scale about 500 times exaggerated in proportion to horizontal scale.

this region; but nothing can be said with certainty in this respect before the subject has been more closely studied.¹⁾

The generally accepted view of leading oceanographers of recent years was that while the current through the Rockall Channel comes from the southwest, across the North Atlantic (as mentioned above p. 67), there is no very distinct current South of Ireland and in the Bay of Biscay [cf. Krümmel, 1911, p. 594, and in *Deutsche Seewarte*, 1902, Pl. 3]. Prof. G. Schott says [1898] that the current in the Bay of Biscay changes with the wind. But further south, off Cape Finisterre and the west coast of Spain and Portugal, the current was supposed to run southwards at a relatively fast rate, forming the Canary Current. This view was based upon observations of surface drift, the distribution of the surface temperature, the atmospheric temperature, the prevailing winds etc., and may perhaps to some extent be correct as regards the circulation of the surface waters. But it is, at any rate, not justifiable to extend the conclusions thus arrived at, to the circulation of the deeper strata.

If the above views as to the currents were correct, we should expect to find a horizontal distribution of salinity in the upper strata of the sea in these regions, which would agree with the direction of the currents. If there is no distinctly prevailing current in the Bay of Biscay, but the water is carried by the "Gulf Stream" from the west, from the North Atlantic, into the Bay, the salinity of the water ought to be very nearly the same there as in corresponding latitudes in the North Atlantic. This is, however, not the case, the water in the Bay of Biscay has much higher salinities and higher temperatures than the North Atlantic water to the west, as is for instance clearly seen if the observations at the Danish station (Fig. 19, Da I) of September 11th, 1906, in 46° 30' N, 7° 0' W (or at the Planet Station 1, of January 26th, 1906, in 46° 52' N, 7° 4' W, see Table p. 61) be compared with the section across the North Atlantic taken by the Murray Hjort Expedition in July 1910 (see Fig. 21), where *e. g.* Station 89 was in 45° 55' N, 22° 24' W, and Station 88 in 45° 26' N, 25° 45' W. The isohaline of 35.50‰ lies there at about 350 metres and the isotherm of 10° C. at about 620 metres descending farther west to about 730 metres (at

¹⁾ The gradients of the isotherms are very small, but it has of course to be considered that as the section is in about 30° N the deflecting effect of the Earth's rotation upon horizontal movements is comparatively small, and a certain gradient of the isopycnals indicates a correspondingly greater velocity of the horizontal movement than in higher latitudes.

Station 90). At the Danish Station Da I in the Bay of Biscay the isohaline of 35.50‰ was at about 1400 metres and the isotherm of 10° C. at about 900 metres (see Fig. 19).

The annual evaporation from the surface of the sea in this region is evidently not in excess of the annual rainfall, which is probably between 1000 and 2000 mm [cf. Supan, 1898]. The only conceivable manner in which the salinity of the surface layers could be appreciably increased in the Bay of Biscay, would be by intermixture with the underlying intermediate layer of Mediterranean water; but this process proceeds very slowly, and would certainly not be able to increase the salinity of the surface layers much if they were coming from the west; and besides in that case we could not expect to find a vertical distribution of salinity as observed at the stations in the Bay of Biscay with a minimum at about 600 metres.

We know that at the Danish Station Da I, of September 11, 1906 in the Bay of Biscay, or at the Planet Station 1, the water at 800, 1000, 1200, and 1500 metres, with salinities between 35.77 and 35.35‰, must have come from the south, as it is Mediterranean water. But there is nothing to indicate that the water above the level of 800 metres, say between 800 and 200 metres, is moving in a direction different from that of the underlying Mediterranean water.

The curves of density of the stations (Fig. 20) exhibit no break at any level, which might indicate different currents; the breaks in the curves of Stations Da III and F 2, are most conspicuous, but they are due to the vertical circulation during the winter, and occur in water strata which we know are moving northward, *e.g.* at F 2, the Frithjof Station 2, in the Rockall Channel. The isopycnals of the section (Fig. 19) through the stations in the Bay of Biscay give similarly no indication of any difference in the movements of the strata above and below the level of 800 metres.

It is thus a justifiable conclusion that in the Bay of Biscay the saline water between the surface layer and 800 metres, as well as the underlying Mediterranean water, comes from the south, and not from the west.

The water of the upper layers at the Planet Station 2, west of Portugal, in 41° 19' N and 11° 31' W (see Fig. 19, P 2), should come from the north or north-west, according to the opinion commonly held. We know that the water at 800 metres, with a salinity of 35.79‰ cannot have come that way, as it is Mediterranean water coming from the south. The curve of density of the station (Fig. 20, P 2) does not

indicate any sudden or radical difference in direction of movement between the water at this level and the overlying water, nor do the isopycnals of sections through the station (cf. Fig. 19) indicate any such difference. It seems thus probable that the water of the higher strata, with salinities between 35.52 and 35.70‰, also comes from the south.

But we may expect the velocity of the current to be much reduced in this region where the sea bottom is very uneven, and there is a ridge or an elevation to the north (see Fig. 18). The core of the current may be expected to lie farther seawards, outside these elevations and depressions of the bottom. This may also explain why the water is warmer farther seawards, and the isotherms frequently are deflected southwards along the coast of Portugal.

At any rate, these shapes of the isotherms cannot be directly due to colder water carried by a current from the north; for if it be not merely a surface drift, such a current would naturally run fastest over deep water, outside the continental shelf, where the sea-bottom offers the least resistance. The greatest mass of colder water from the north would then be over the deep sea, and not near the coast. But owing to the effect of the Earth's rotation, the surface layers of the current would be thicker on its right-hand side, and the heavier and colder underlying water would be nearer to the surface on the left side of the current, or near the land. In this manner there might possibly be comparatively low temperatures near the coast, not directly owing to water coming from the north, but owing to the underlying water being lifted.

There are, however, so few observations from this region, that we can say nothing definite as to the direction and details of the currents. As the prevailing winds of this region are directed landwards, both summer and winter, and partly south-eastwards, at least in the summer, we may expect that the drift current on the surface is frequently directed southwards along the coast; but this current is probably of no great depth.

The above study of the known serial soundings along the west coast of southern Europe, and of the far too few sections of the eastern North Atlantic, constructed on the basis of known observations, has thus led us to the conclusion that, at depths between 150 or 200 metres and say 1500 metres, there is a northward flow of water along the continental slope off the west coast of Europe, from the region of the Spanish Bay, or even from the sea between Madeira and the Azores.

If this be such a simple conclusion from well known sections, as *e. g.* Schott's section of the North Atlantic, one may wonder why it has not been generally accepted before. The fact is, however, that very few oceanographers have fully realized how much vertical sections of the Ocean may tell them as to the horizontal movements of the water. Studying chiefly surface observations, and thinking that all oceanic currents are chiefly, if not entirely, created by the winds, most leading oceanographers have taken it for granted that the currents of the surface layers were practically the same, at least as to direction, as those of the deeper strata, and it was not even understood that the effect of the Earth's rotation would necessarily have a tendency to alter the direction of the wind-created currents with the depth.

If we look at it from a dynamical point of view, it seems probable that such a northward current along the continental slope off the west coast of southern Europe must arise; for the mean density of the water, between the surface and say 1500 metres along the slope, is much lower in the south, *e. g.* between 30° and 40° N Lat., than farther north, *e. g.* in 50 or 56° N Lat.

The curves of Fig. 20 (p. 64) represent the vertical distribution of density between the surface and 1500 metres at the following stations: *P 6* = Station 6 of the Planet Expedition of February 8, 1906 (in $35^{\circ}5'N$, $20^{\circ}45'W$, see Fig. 18); *P 2* = Station 2 of the Planet Expedition, off Portugal (see Figs. 18, 19); *Da I* = the Danish station of September 11th, 1906, in the Bay of Biscay (see Figs. 18, 19); *Da III* = the Danish station of June 5th, 1906, southwest of Ireland (see Figs. 18, 19); *F 2* = our Station 2 of the Frithjof Expedition. The curves show that the density of the water increases much for each station northwards.

The force of circulation thus existing, will have a tendency to carry the water from the south northwards.

This tendency may be counteracted by the forces creating the Northern Equatorial Current, carrying water westwards.

They are, 1) the friction on the sea surface exerted by the Trade Winds, and transferred to the underlying strata by the friction of the moving water, — and also 2) the westward deflecting effect of the Earth's rotation upon the water rising to the surface from below in these regions [cf. Nansen, 1905]. But it is improbable that these forces, existing in the regions of the Equatorial Current, should be able to check entirely the force of circulation of the water strata so far

north as, *e. g.* in about 35° N, and it seems probable that a northward flow must arise there.

Owing to the effect of the Earth's rotation the northward moving water will be deflected towards the right against the continental slope; the greater the velocity of the water and the higher the latitude, the more will this deflection be. The water will, therefore, flow northwards along the slope; and we have here probably an example of an oceanic current caused exclusively by the difference of density, and moving against the direction of the force exercised by the prevailing winds.

The above mentioned fact that the Mediterranean water, carried by the undercurrent through the Straits of Gibraltar, may be traced northwards as far as Ireland, is the most unmistakable proof that at least at depths between 800 and 1500 metres the water is continually flowing northwards from the Spanish Bay along the eastern border of the North Atlantic and into the Rockall Channel. But as there is no indication whatever of a difference between these intermediate water-strata and the overlying strata as to the direction of their horizontal movements, it is justifiable to infer that the water of the strata between say 100 metres and 800 metres is also flowing northwards.

The intermediate layer of Mediterranean water with salinity above 36.00‰ , extends only a very short distance towards the south-west from the Straits of Gibraltar, while it extends northwards past Cape Finisterre, according to Helland-Hansen's chart showing the salinity at a depth of 500 fathoms or 914 metres [Murray and Hjort, 1912, p. 296]. But the water with salinities between 35.50 and 36.00‰ has in this chart a much wider distribution towards the south-west and west. It may be doubtful whether all of this water with salinity above 35.50‰ is actually derived from the intermediate layer of Mediterranean water, as it may to some extent be derived from the top-layers which have also very high salinities in this region of the sea, cf. Helland-Hansen's sections westwards from the Canary Islands, and across the Spanish Bay [Murray and Hjort, 1912, p. 84, 293, and 294]¹).

Considering the formation of the sea-bottom it is, however, to be

¹) The vertical section westwards from the Canary Islands [1912, p. 84] seems to prove that the isohaline of 35.50‰ is drawn somewhat too far south in the chart for 500 fathoms [1912, p. 296], as the water with salinity above 35.50‰ does not descend deeper than about 700 metres at Station 46 or at any other station of the section.

expected that the deep water sinking down along the slope from the Straits of Gibraltar would have some tendency to move towards the south-west in spite of the effect of the Earth's rotation, as the moving water may probably find the line of least resistance along the deep channel, more than 4400 metres deep, passing towards the south-west from the Spanish Bay, with a series of banks, the Gettysburg Bank (Gorringe Bank), the Hayward Bank, the Josephine Bank, the Seine Bank, and the Madeira Island-group, on its north-western side. These banks, and the elevations or low ridges on the sea-bottom on which they are situated, will offer a great deal of resistance to the northward movement of the water. Some part of the water, following the line of least resistance, will therefore probably flow along the deep channel south of the banks and Madeira, and will flow northwards between Madeira and the Azores. At the depth of 800 and 1000 metres, however, there can be no distinct current in the direction of the Canary Current; for in that case the intermediate layer of Mediterranean water would have had a wide distribution towards the south-west. West of Madeira there must evidently be a flow towards the north and north-east, carrying the Mediterranean water in that direction; while this water also extends some distance westwards towards the Azores, the movements of the water strata being probably somewhat complex as is generally the case in the ocean, especially where the form of the bottom is as uneven as it is in this region. Thus there may be great vortex-movements and other complications.

The observations made during the Planet Expedition at Stations 5 and 6, on February 5th and 8th, 1906, support the above view. Station 5 was near the eastern slope of the Hayward Bank (in $34^{\circ}46'N$, $11^{\circ}9'W$), and west of the Spanish Bay. The intermediate layer of Mediterranean water was there well developed with a salinity of 36.09‰ at 1000 metres. Station 6 was about 240 naut. miles, or 440 kilometres, to the south-west of Madeira, in $30^{\circ}5'N$, and $20^{\circ}45'W$ (see Fig. 18). At this station no trace of the intermediate layer of Mediterranean water was observed, evidently because there is no motion of the water in that direction, the Mediterranean water passing south of Madeira rounds the platform of this island, and flows northwards west of it.

No serial observations have been published which give any trustworthy information as regards the horizontal motion of the water at depths between the surface and the intermediate Mediterranean layer in this region of the ocean. If anything, the isotherms of the charts,

e. g. for the depths of 150, 200, and 400 metres, which Dr. G. Schott [1902, Pls. XII—XIV] has constructed on the basis of previous observations, might indicate a movement towards the north-east in the region west of the Canary Islands and Madeira, and there is hardly any indication in these charts of a movement in the direction of the so-called Canary Current, which seems to be a very superficial drift current. Schott's charts, particularly those for 200 and 400 metres, may rather indicate a cyclonic motion of the water, with a south-eastward motion south of the Azores and a north-eastward motion west of the Canaries and Madeira. In the middle, between these two island-groups and the Azores, there would then be somewhat colder water, lifted from below, because we would there be on the inner side of the cyclonic motion, *i. e.* on the left hand side of the currents.

It is of much interest that the conclusions here arrived at as to the directions of the currents in this region, are in an unexpected manner supported by direct current measurements made by Dr. B. Helland-Hansen in June 1910, during the Murray Hjort Expedition, as he himself has pointed out to me upon hearing the results of my investigations. South of the Azores, at Station 58, in $37^{\circ} 37' \text{ N}$, $29^{\circ} 25' \text{ W}$, he made a number of current-measurements throughout one complete tide-period. At a depth of 10 metres, 70 measurements were made during nearly 14 hours; the results of the motions observed show a general drift of the water towards the south-east, with a mean velocity of 8—9 cm. per second (about 4 miles or 7 kilometres in 24 hours) [see 1912, Fig. 181 and p. 272]. This motion is exactly in the direction which we might expect according to our above views.

West of the Canaries, at Station 49 C, in $29^{\circ} 7' \text{ N}$, $25^{\circ} 32' \text{ W}$, a number of measurements of currents were made during five hours and a half [see 1912, p. 266]. The resultant of the motions observed at the depth of 10 metres seems to have been directed towards the north-east, which is just the direction in which we might expect the current to flow at this place if our views are correct. But the latter observations were not so reliable as the former ones, because they were continued during too short a period, and moreover the ship was not anchored as at Station 58, but was drifting with a bag-net (3 metres in diameter) lowered to 1000 metres as a drift-anchor, and the current-measurements had to be made by two current-meters simultaneously at two different depths, the deeper ones of which were 1830 metres or 915 metres, while the depth of the sea was about 5000 metres; and we do not know what the motions of the water might have been at 1830 or 915 metres.

As was mentioned before, the generally accepted view as to the circulation of the North Atlantic water, and the so-called "Gulf Stream" west of Ireland, was based chiefly on observations made on the sea-surfaces. It may, however, be doubtful whether the surface observations in the North Atlantic really do altogether corroborate that view. It seems to me that the horizontal distribution of the surface salinity, as it is now known by the international cooperation for oceanic research, must necessitate essential modifications in several respects; and I think that it gives an altogether unexpected support to our view as to the northward flowing current along the west coast of southern Europe. I may especially mention the interesting investigations of the North Atlantic surface-salinities published by Mr. Donald J. Matthews [1907], and the continuation of these researches published, with charts, in *Bulletin Trimestriel* (Conseil Permanent International, Copenhagen). Matthew's gives in his paper, 16 charts showing the horizontal distribution of salinity and temperature of the North Atlantic surface-water from September 1904 to December 1905. In no less than 8 (*i.e.* 50%) of these charts, the surface water with salinity above 36.00‰ extends comparatively far north off the west coast of Spain, and forms a wedge into the Bay of Biscay, or even approaches Ireland; the charts for November and December 1905, and for February, March, May, July, and August may be particularly mentioned. In some of the other charts there are also indications of similar conditions. The charts for Nov. and Dec. 1904, Jan., Febr., March, and May 1905 are here reproduced (Figs. 24—29). I think that it is justifiable to say that the distribution of the surface salinity, as indicated by the isohalines of 36.00 and 35.50‰ in these charts, is exactly as we would expect it to be if there is a current running northwards along the continental shelf off the coast of Portugal, Spain, France, Britain, and Ireland.

The charts for February to May 1905, seem especially to illustrate the course of this current. It is striking that the isohaline of 36.00‰, in most charts, curves northwards some distance west of the coast of Portugal and Spain, leaving a belt of water with lower salinity near the coast. This is also what might be expected, owing to the coast water and to the elevations and roughness of the bottom off this coast; as was mentioned above. All this agrees remarkably well with our view as to a northward flowing current in this region.

It should be kept in view that the vertical circulation during the winter carries water from the underlying strata to the surface, and the distribution of the surface salinity in the winter months, after January,

Fig. 24. November, 1904.

Fig. 25. December, 1904.

Fig. 26. January 1905.

Fig. 27. February 1905.

Fig. 28. March 1905.

Fig. 29. May 1905.

Salinity and Temperature of the North Atlantic Surface Waters during November 1904—May 1905 [Matthews, 1907].

may therefore be expected to give a more correct idea of the deeper currents than the distribution of the surface salinity in the summer, when it is more influenced by the surface drift.

The shapes of the isotherms of the sea surface in the charts, do not indicate a northward flow of the water, along the west coast of southern Europe, to the same extent as the isohalines. This is what might be expected, because the temperature of the sea surface is changed much more easily than the salinity. But as the earlier representations of the surface circulation of the ocean are to a very great extent based upon the observations of the surface temperatures, it is natural that a study of the distribution of the surface-salinity will greatly modify or alter these representations.

The waters of the shallow English Channel are naturally to a very great extent influenced by the strong tidal currents and by the local winds; but the interesting charts of Matthews [1905, 1909, 1911] of the surface salinity show distinctly a very regular flow of saline water from the south-west, past Ushant, into the Channel, and a narrow continuation of this current northwards along the coast of Cornwall, past the Land's End, probably joining a vortex-movement in the Irish Sea. Matthews identifies [1905, p. 323] the current "setting in a northward direction from some point near Ushant" with "what has long been known under the name of Rennel's current". It seems to me to be evident that this northward current past Ushant, is a side branch of a northward flow, along the continental slope, in the Bay of Biscay, and that consequently this northward flow may very frequently also be traced in the distribution of the surface salinity, in spite of the surface drifts in the opposite direction mentioned by several authors [cf. Krümmel, 1911, p. 594 *et seq.*].

In some of the charts of the North Atlantic, published by Matthews [1907], the surface water with salinity above 36.00 ‰ has a very peculiar northward extension near 30° W Long., northwest of the Azores. This is especially conspicuous in his charts for February and March 1905 (Figs. 27, 28; see also the chart for May 1905, Fig. 29). As these are the months in which the vertical circulation caused by the cooling of the sea-surface is most developed, the charts for these months may be expected to give the most trustworthy representation of the horizontal distribution of the salinity, not only on the surface, but also in the upper layers of the ocean.

A comparison between Matthew's charts for February, March, and May 1905 and a bathymetrical chart of the ocean (see Fig. 18),

will show that this northward extension of the water, of salinity above 36.00‰ , coincides very nearly with the western slope of the ridge extending northwards from the Azores, at depths of between 2000 and 2300 metres. It is a feature frequently observed, that elevations of the sea bottom, even at considerable depths, may have a marked influence upon the direction of the currents and the circulation of the sea, even near its surface. It is therefore certainly not a mere accident that the saline water above 36.00‰ in Matthew's charts has such a conspicuous northward extension just in this region, for we must expect that water carried by the current from the west is greatly hindered in its eastward course by this ridge and the Plateau of the Azores rising from the Western Atlantic Basin, 4000 and 5000 metres deep, to depths of between 2300 and 1500 metres, or less. While a portion of the water may continue its eastward course across the ridge, some part of it will be deflected northwards along the western slope of the ridge; but owing to the effect of the Earth's rotation this water will be pressed towards the right, until farther north, where the ridge is somewhat lower, a great deal of it is gradually carried north-eastwards and eastwards across the ridge.

Another portion of the water flowing from the west towards the Plateau of the Azores, may be deflected southwards along the ridge, and may partly join the vortex movement of the Sargasso Sea, partly flow eastwards south of the Plateau of the Azores, and may join the north-east flow between the Azores and Madeira, forming the northward current along the west coast of Europe. South-west of Ireland this current may meet the water carried eastwards across the Atlantic Ridge to the North of the Azores. But while the current coming from the south is very deep, the drift current from the west is probably more of a surface current. The waters of both currents join and form the Irish Current through the Rockall Channel.

The international surface charts of the North Atlantic for the years 1906 to 1910, published in Bulletin Trimestriel (or Bull. Hydrographique), Copenhagen, may to some extent support the above view, cf. especially the charts for February 1906, May, August, and November 1907, May, August, and November 1908. In these maps the isohaline of 36.00‰ , exhibits indications of the same two northward extensions or wedges of saline water (above 36.00‰).

The surface charts of the North Atlantic published by H. N. Dickson [1901], and showing the horizontal distribution of temperature and salinity in each month for 1896 and 1897, were based upon less com-

plete series of observations, and less accurate determinations of the salinity, because the methods at that time were not so well developed as they are now. But the water of salinity above 36.00‰ in Dickson's charts exhibits indications of the same two northward extensions, near 30°W Long. and near the Bay of Biscay, as above. His isotherms, especially that of 15°C ., give perhaps still more distinct indications of this kind, see the charts for December 1896, February, March, May, and June, 1897.

If the above view as to a probable northward flow, north-west or north of the Azores, be correct, we may expect to find indications of this current in a section across the North Atlantic. The section from Newfoundland to Ireland taken during the Murray Hjort Expedition (see Fig. 21, p. 68), in July 1910, passes through a region of interest in this respect.

Between Stations 85 and 86, in $47^{\circ}25'\text{N}$, and $30^{\circ}20'\text{W}$, just over the western slope of the Atlantic Ridge, the isotherms and isohalines and consequently also the isopycnals, fall very steeply eastwards, indicating that the water strata between the surface and 1600 metres were moving in some northerly or north-easterly direction with comparatively great velocities. But this is just the region where, according to the above views, there should be a northward current, and where the saline water (above 36.00‰) frequently has a northward wedge in the surface charts. Thus the section of the Murray Hjort Expedition gives an almost unexpectedly strong confirmation of the correctness of our views.

It has been mentioned above that towards Ireland the equilines of the above section slope eastwards, indicating a northward current along the continental slope, at least at depths greater than 200 metres, while the movements of the surface layers may have had a somewhat different direction.

At Station 90, in $46^{\circ}58'\text{N}$ and $19^{\circ}6'\text{W}$, all equilines at depths greater than 200 metres, exhibit a very deep descent, indicating that the water was probably moving in some northerly direction west of this station and in some southerly direction east of it. The rise — *e. g.* of the isotherm of 10°C . — between Stations 90 and 91, being about 400 metres, it is hardly possible that it could be due to some intermediate wave, or similar temporary disturbance of the equilibrium of the strata. It is therefore most probably due to some kind of vortex-movement; Station 90 may have been near the centre of a great anti-cyclonic vortex, or Station 91 may have been near the centre of a cyclonic one.

Fig. 30 gives a hypothetical representation of the directions of the water motions at depths of about 400 metres in the North Atlantic,

Fig. 30. Salinities and Temperatures at a depth of 400 metres. Based chiefly upon the observations of the Murray Hjort Expedition 1910, combined with the observations of the Fridtjof Expedition and the Fram Expedition 1910, the Danish Thor Expeditions 1905 and 1906, the Challenger Expedition 1873, the German Expeditions of the Planet 1906, the Valdivia 1878, the Gazelle 1874, and others. The arrows indicate the probable directions of the motion of the water.

according to the conclusions arrived at above. The representation of the distribution of salinity and temperature is to a very great extent

based upon the observations of the Murray Hjord Expedition 1910 (cf. Helland-Hansen's chart for 200 fathoms [1911, p. 452; 1912, p. 296]), to which all available observations of other recent expeditions have been added, besides the temperature-observations of earlier expeditions, particularly those of the Challenger. A comparison between this chart and the bathymetrical chart (Fig. 18, p. 61) shows to what a great extent the distribution of salinity, and consequently the water movement, at a depth of 400 metres are probably influenced by the configuration of the bottom, even at depths of 2000 and 3000 metres.

It is indeed strange how often we find that there is nothing new under the sun. After I had arrived at the above conclusions as to the course of the currents, I found that very similar views as to a current from Spain *via* the Bay of Biscay to Ireland were most ably advanced by Mr. James Rennell about a hundred years ago [1793, 1815]. He based his opinion upon the "sets" or drift of ships, drift of bottles, and similar surface observations.

It was thus the surface current only that Mr. Rennell discussed, and he expressly said [1815, p. 191] that "the current does not exist in strength, but at certain intervals".

As described above, my examination of the observations hitherto published, has led me to the conclusion that in the strata below the surface strata, a permanent current is running very much in the same direction as Rennell's current, while the currents of the surface layers may be very variable.

Prof. J. Thoulet [1898, p. 295], studying the sediments of the continental shelf of the Bay of Biscay, came to the conclusion that the presence of Magnetite in the sediments of the shelf off the French coast, proved that a "submarine" current is running eastwards along the north coast of Spain, and then turning towards the north-west and west-north-west in the inner end of the Bay of Biscay (or Gulf of Gascogne). But this "submarine" current, he thought, had the opposite direction to the surface current, "the existence of which was established by all observations". In this connection the possibility should, however, be pointed out that, although a current is running southwards near the coast, there may very well be a northward current farther seawards, because a current along the edge of the continental shelf may easily create a reactionary current in the opposite direction nearer the shore.

The existence of the Rennell Current has been disputed by modern, especially German oceanographers, and Krümmel [1911, p. 595] says

that, "Nach alledem wäre es endlich an der Zeit, den Rennellstrom von den Karten zu tilgen". But I think that Matthews is certainly right in seeing a continuation of the Rennell Current in the regular flow of saline water northwards into the English Channel, past Ushant, and likewise northwards into the Bristol Channel, past the Lands' End.

Some forty years ago the origin and causes of the warm oceanic current, generally called the Gulf Stream, west of the British Isles, was much discussed, especially in England. It was generally acknowledged that the amelioration of the climate of Europe was due to this current, and most oceanographers of the time, as well as later, were of the opinion that it was a continuation of the Gulf Stream through the Florida Strait (perhaps joined by the West Indian Current), travelling directly across the North Atlantic. Their view was, that this, as well as all other great ocean currents, was created solely by the winds. Some oceanographers thought that the trade-winds, creating the Northern Equatorial Current, were also the chief cause of the Gulf Stream, its water travelling across the Atlantic chiefly on account of the impetus or *vis à tergo* it had obtained from the Equatorial Current¹); while others objected that this *vis à tergo* was certainly not sufficient to drive the water from the Strait of Florida across the North Atlantic, to the coasts of Europe. It was contended [*e. g.* by Findlay, 1869, p. 107] that by the time the Gulf Stream, from the Strait of Florida, has reached the sea south of the Newfoundland Banks, it is so thinned out and expanded that it can be no longer recognised beyond this region. The north-easterly drift which reaches the shores of northern Europe, must therefore be produced by other causes, and these were the so-called anti-trades or the south-westerly winds across the North Atlantic, prevailing in these latitudes.

In opposition to these views Dr. W. B. Carpenter [1871, 1872, 1874 etc.] maintained that the north-east flow, off north-western Europe, cannot be "an extension or prolongation of the Gulf-Stream, still driven on by the *vis à tergo* of the trade-winds". He regarded "a large part, if not the whole", of the north-east flow "as quite independent of that agency". While admitting that the winds may create currents — *e. g.* the trade-winds creating the Equatorial Currents and the Florida Current — Carpenter held the opinion that the general

¹) Cf. John Herschel. [1861], Wyville Thomson, [1874, p. 356 *et seq.*], Petermann, [1870], Croll [1870 etc.]. At that time the deflecting force due to the Earth's rotation was not sufficiently recognized, and consequently it was not understood that this force alone would make a theory such as the above perfectly impossible.

circulation of the Ocean was chiefly sustained by difference of temperature, and he thought that the action of the cold upon the water of the polar areas had even a greater circulating effect than the heating of the surface layers in the tropical regions. He does not definitely state from which area of the North Atlantic the north-east flow originated; but his idea evidently was that off the west coast of southern Europe, *i. e.* Portugal and the Spanish Bay, there is, what he called a neutral area, where the temperature of the sea was not higher than the normal temperature of the latitude. From this area he thought the water masses of the upper strata, down to 700 or 800 fathoms (1280—1460 metres), flowed northwards, towards the polar regions, ameliorating the climate of north-western Europe, and the evidence of climatic amelioration increases in proportion as we pass northwards from the neutral area.

Before Carpenter, several eminent physicists had pointed out the importance of difference of density (or temperature) for oceanic circulation, *e. g.* Arago already in 1838, and Pouillet [1847, II, p. 667] in 1847. Professor Lenz [1847] had also pointed out the principles of the thermal origin of the general oceanic circulation. Similar views had been held forth by Professor Buff [1851] and Captain Maury [1860], though by the latter in a somewhat confusing manner, as he did not clearly distinguish between the difference of density caused by temperature and that caused by salinity. Amongst the many others who have supported the theory of the thermal origin of the oceanic circulation, may be mentioned Ferrel after 1856 [1882], Sary [1868], A. Mühry [1869], and others. Even Leonardo da Vinci had already expressed similar views. In Denmark the influence of the difference of temperature (and density) upon oceanic circulation has been pointed out by Prof. Colding [1870], and in Norway Prof. Cato Guldberg published a note-worthy paper on the same subject [1872].

Dr. Carpenter's views met with much opposition [cf. Wyville Thomsen, 1874; Croll, 1871, 1874]. The theory of the winds as the *vera causa* of sea currents and of the general oceanic circulation, has since that time been prevalent amongst oceanographers, especially after Zöppritz having given it an apparently more scientific foundation [cf. W. Ekman, 1905, 1906], while Carpenter's theory of the north-east flow along western Europe has been more or less forgotten.

The fact may be, here, as so often, that the truth lies between the two views, and that there is something to be found correct in each of them.

The researches described above, have led to conclusions, which to a very great extent prove Dr. Carpenter right. There is really a deep current, 1500 metres deep, flowing northwards along the west coast of Europe, very much in the same manner as assumed by him, and forming to a great extent the current through the Rockall Channel, *i. e.* the Irish Current. This deep current is chiefly caused by difference of density of the water; due to difference of temperature, as was assumed by Carpenter. But, on the other hand, there is undoubtedly also an easterly surface drift across the North Atlantic, with a branch at about 50° N, joining the Irish Current.

VIII. Variations in the Temperature of the Irish Current in different years.

The observations made hitherto in the Rockall Channel are not sufficiently numerous to afford much information as to the variations in the temperature of the Irish Current, especially as the observations of different years were not taken along the same line across the current.

Really trustworthy conclusions as to these variations, can only be based upon vertical sections, with a sufficient number of stations and observations, taken in different years along the same line across the current; but we have no such sections. Considering the great differences in the temperatures at stations in the Frithjof Section of the Rockall Channel, with but short distances between them, it cannot be expected that conclusions of much value in this respect can be based upon a comparison of the observations at isolated stations.

The observation-material of earlier years is the following: the section of the Porcupine Expedition across the Rockall Channel, taken in the end of June, 1869, some distance to the south-west of the Frithjof Section I (see Fig. 1 P); the observations at several Danish Stations in the Rockall Channel in May, June, and August 1905; a few Irish Stations in May and November 1905; the Danish Station of May 28, 1908, in the middle of the Rockall Channel (see Fig. 7), some distance north of the Frithjof Section.

The curves in Figs. 31—36 represent the temperature-observations at several stations of these different years, and the observations at the nearest stations of 1910.

The curves of the Porcupine Stations (Fig. 31) have very much the same character as the curves of the Frithjof Station 1, 3, and 4, while they differ from the curves of Stations 2 and 5, where the temperatures were on the whole much lower. Being to the south of the Frithjof Stations, the Porcupine Stations ought to have had higher tem-

Fig. 31. Vertical Temperature Curves of the Porcupine Stations 19–22; and of the Frithjof Stations 3 and 5.

peratures, unless the water of the Irish Current was colder in June 1869 than in July 1910.

As the Porcupine temperatures are on the whole considerably higher than those of the Frithjof Stations 2 and 5, while they are to some extent very similar to, or even lower than those at Stations 1, 3, and 4 (see Fig. 31), it is difficult to say what has been the case; it may perhaps indicate that the current was colder in the summer of 1869, than in the summer of 1910.

The Danish Station 60 of June 11, 1905, (in $56^{\circ} 0' N$, $9^{\circ} 57' W$) and the Danish Station of June 23, 1906 (in $55^{\circ} 45' N$, $9^{\circ} 35' W$) were nearly in the same locality as the Frithjof Stations 2 (in $55^{\circ} 53' N$, $10^{\circ} 0' W$) and 1 (in $55^{\circ} 48' N$, $9^{\circ} 25' W$). The difficulty is, however, that the temperatures at both Danish Stations are on the whole lower than those of Station 1, but higher than those of Station 2.

Fig. 32. Vertical Temperature Curves of the Danish Stations **Da 60** (of June 1905) and **Da** of June 23, 1906; of two Irish Stations (**Ir**) of May (**Ir 23**) and November 1905; and of the Frithjof Stations **F 1** and **F 2**.

The curves of Fig. 32 may perhaps indicate that the current was warmer in June 1905 than in June 1906; and if we take the mean values of the two curves of 1910, the current should then have been somewhat colder than in 1905 but slightly warmer than in 1906.

Two curves representing the observations at the Irish Stations of May 20, and November 18, 1905, (in $55^{\circ} 1' N$, $10^{\circ} 45' W$, and in $54^{\circ} 59' N$, $10^{\circ} 53' W$) are also given in Fig. 32, but no certain con-

clusion can be drawn from them. The Irish temperature-readings for the greater depths, those deeper than 1000 metres, seem doubtful.

The Danish Station of May 28, 1908, in $57^{\circ} 2' N$, $11^{\circ} 19' W$, was midway between the Frithjof Station 3 (in $56^{\circ} 3' N$, $11^{\circ} 10' W$) and Station 101 of the Murray Hjort Expedition [cf. 1912, p. 222, 242], of August 7, 1910 (in $57^{\circ} 41' N$, $11^{\circ} 48' W$), as well as the Danish

Fig. 33. Vertical Temperature Curves of the Danish Stations Da 58 (of June 1905) and Da of May 28, 1908; of the Murray Hjort Station MH 101 (of Aug. 1910); and of the Frithjof Stations F3 and F4 (of July 7, 1910).

Station 58 of June 7, 1905, in $57^{\circ} 47' N$, $11^{\circ} 34' W$. The curves of Fig. 33 seem to indicate that the current was warmer in the summer of 1908 than in the summer of 1910, when it was perhaps slightly colder than in 1905.

Some Danish Stations of May and August 1905 [see Nielsen 1907, p. 4—5] were near the localities of some stations of Amundsen's northern section of July 1910. The Danish Station 53, of May 30, 1905

(in $59^{\circ}15'N$, $7^{\circ}23'W$), was only a short distance south of Amundsen's Station 23, of July 6, 1910 (in $59^{\circ}27'N$, $7^{\circ}27'W$), and his Station 22 (in $59^{\circ}26'N$, $7^{\circ}50'W$), while the Danish Station 52, of May 30, 1905 (in $59^{\circ}49'N$, $8^{\circ}58'W$), was at a somewhat greater distance to the north-west of Amundsen's Station 21 (in $59^{\circ}25'N$, $8^{\circ}32'W$). The temperature curves of these stations are given in Fig. 34, with the

Fig. 34. Vertical Temperature Curves of the Danish Stations **Da 52** and **Da 53** of May 30, 1905; and of the Fram-Stations (Amundsen's Stations) **A 21** and **A 22** of July 6, 1910.

the Amundsen stations, the difference in the temperature of the current may possibly not have been as great as indicated by the curves of Fig. 34.

The curve of the Danish Station 52 shows on the whole lower temperatures than the curves of the Amundsen Stations, but not lower than might be expected owing to the more north-western situation. If we take the mean values of the curves of the two Danish Stations, they will on the whole be somewhat higher than those of the Amundsen stations at depths greater than 100 metres.

According to the observations at the two Danish stations and at the three nearest Amundsen stations, it seems thus probable that the water of the Irish Current in this region was somewhat warmer in the summer of 1905 than in that of 1910.

A comparison between the temperature curves of the Danish Station 124 of August 30, 1905 (in $58^{\circ}53'N$, $10^{\circ}15'W$), the Amundsen Stations 19 (in $59^{\circ}13'N$, $10^{\circ}44'W$) and 20 (in $59^{\circ}19'N$, $9^{\circ}14'W$) of July 5 and 6, 1910, and the Scottish Station K (in $58^{\circ}43'N$, $9^{\circ}45'W$) of August 23, 1910, as represented in Fig. 35, may, however, give the opposite impression, viz: that the current was warmer in July and particularly in August 1910, than in August 1905.

The temperature curves of the Scottish Station L (in $57^{\circ} 59' \text{ N}$, $10^{\circ} 34' \text{ W}$) of August 24, 1910, and the two nearest Danish Stations 57 (in $57^{\circ} 45' \text{ N}$, $9^{\circ} 57' \text{ W}$) of June 7, 1905, and 125 (in $57^{\circ} 46' \text{ N}$, $9^{\circ} 55' \text{ W}$) of August 31, 1905, represented in Fig. 36, may also give the impression that the water of the Irish Current was warmer in August 1910 than in June and August 1905.

Fig. 35. Vertical Temperature Curves of the Danish Station **Da 124** (of Aug. 1905); of the Scottish Station **Se K** (of Aug. 1910); and of the Fram Stations **A 19** and **A 20** (of July, 1910).

We thus see that it is difficult to draw any certain conclusions as regards the annual variations in the temperature of the Irish Current owing to insufficient material of observations from previous years. The observations seem, however, to prove that there have been no great variations in those few years in which observations were taken.

For the sake of comparison, I may here add the mean temperatures of the winters (November to April) at Valentia on the south-western

coast of Ireland, at Markree Castle on the north-western coast of Ireland, in 54°11' N, 8°27' W, and in Glasgow.

Winters	1904-05	1905-06	1906-07	1907-08	1908-09	1909-10	1910-11
Valentia	8.0° C.	7.5° C.	7.6° C.	7.3° C.	8.1° C.	6.9° C.	7.3° C.
Markree Castle .	6.1° "	5.5° "	6.0° "	5.4° "	6.0° "	4.8° "	5.4° "
Glasgow	5.4° "	5.1° "	5.2° "	4.8° "	5.3° "	4.4° "	5.1° "
Mean	6.5° C.	6.0° C.	6.3° C.	5.8° C.	6.5° C.	5.4° C.	5.9° C.

Fig. 36. Vertical Temperature Curves of the Danish Stations **Da 57** and **D 125** (of June and July 1905); and of the Scottish Station **Sc L** of Aug. 24, 1910.

If we take the temperatures for January, February, March and April of the preceding winter and November and December of the following winter, for each year, we obtain the following mean values:

Year	1905	1906	1908	1910
Valentia	7.8° C.	7.5° C.	8.3° C.	7.2° C.
Markree Castle	6.0° "	5.6° "	5.8° "	5.2° "
Glasgow	5.6° "	5.0° "	5.1° "	4.7° "
Mean	6.5° C.	6.0° C.	6.4° C.	5.7° C.

If we assume that the temperature of the sea-water, found in the Rockall Channel in the different summers, should have influenced the air-temperature of the west coast of Ireland of the preceding winters, the sea ought consequently to have been warmest in the summer of 1905, slightly colder in 1906 and 1908, and coldest in 1910.

If we assume that the temperature of the sea-water, found in the Rockall Channel in the summer, influences the temperatures of the following winters on the west coast of Ireland and Scotland the sea should have been warmest in the summer of 1908, somewhat colder in 1906, still colder in 1905, and coldest in 1910.

If we assume that the temperature of the sea-water, found in the Rockall Channel in the summer, influenced the latter part (January to April) of the preceding winter as well as the first part (November—December) of the following winter, the sea in the Rockall Channel should have been warmest in 1905, slightly colder in 1908, still colder in 1906, and coldest in 1910.

IX. The North Atlantic between the Rockall Bank and Iceland.

There is a small body of water with salinity above 35.30‰ west of the Rockall Bank in our Section I. Whence this water had come, and in what direction it was moving, is somewhat difficult to decide, as the slopes of the isopycnals give no certain information.

According to what was said before (p. 25 *et seq.*) about the cooling of the water over the Rockall Bank, an area with a maximum of density is formed there during the winter.

The lighter water of the surrounding sea will consequently have a tendency to overflow this colder and heavier water, which will sink and be replaced by warmer water, partly from below, partly from the sides. In this manner there might be a tendency, at least during some part of the winter, towards the formation of a cyclonic vortex-movement of the water round the Rockall Bank.

If the presence of the water with salinity above 35.30‰ west of the bank could be thus explained, it would have come north of the bank, and be moving slowly in a southerly direction. This would also to some extent correspond with the shape of the isopycnal of 27.40 which slopes gently westwards from Station 8.

I consider it, however, to be more probable that this saline water had come from the south. By the resistance offered by the Rockall Bank to the water moving north- and north-eastwards, it would seem very probable that the water is to some extent blocked up, and some portion of it is carried to the west of the Rockall Bank (in a similar

manner to the warm saline water west of the Faeroes), but its movement is very slow.

Some small portion of this water may have been carried still farther westward by some vortex-movement.

The small body of water with salinity above 35.30‰, occurring in the region of Stations 10 and 11 in Section I (Pl. X), may be thus explained (cf. the charts for depths of 0, 50, 100 and 200 metres, Pls. II—V).

Fig. 37. Vertical Temperature Curves of the Frithjof Stations 8—12.

The undulations of the isopycnals near the surface (Pl. XI), in the upper 100 metres of water, may to some extent be due to intermediate waves at the boundary between strata with different densities. But the undulations may also more or less indicate horizontal movements and vortex-movements of the water. A striking feature in the western part of Section I and the southern part of Section II (Pl. XII), is the comparatively great uniformity in salinity, temperature, and density between 100 or 200 metres and 800 or 900 metres. As was pointed out before (p. 18), this is evidently to a great extent due to the cooling of the sea-surface during the winter, creating convection currents which may penetrate to great depths in this sea where the differences of salinity are so small.

The effect of this vertical circulation may be seen in the shape of the temperature curves of the different stations (Figs. 37, 38).

These temperature curves also demonstrate the changes in temperature from one station to another. At Station 8 the temperatures between 200 and 100 metres are comparatively low, owing to the cold water from the Rockall Bank. At Station 9 they are higher but then they are lower at the stations further west in Section I (Fig. 37), and decrease still more northwards towards Iceland at the stations of Section II (Fig. 38).

Fig. 38. Vertical Temperature Curves of the Frithjof Stations 12–18.

The fairly uniform salinity is to a great extent about 35.25‰ in the western part of Section I, and about 35.17‰ in Section II, at depths between 200 and 800 metres,

The shapes of the isopycnals in both sections seem to indicate that the horizontal movements of the water are on the whole very slow at all depths in this region of the North Atlantic. The fact that the temperature is slowly decreasing northwards towards Iceland in Section II, makes the isopycnals of 27.50, 27.60, and 27.70 rise in that direction (see Pl. XIII). If there were anything resembling what we have called a lateral equilibrium, in this region, the rise of the isopycnals would prove that the whole mass of water, at levels deeper

than 200 metres, between Stations 12 and 16, was in slow motion in some easterly direction, which would also agree with the direction of the prevailing winds. But it is hardly probable that such an approximate equilibrium exists, because the northward decrease of temperature is evidently to a great extent due to the greater cooling of the sea in the northern latitudes each winter, and also to intermixture with colder deep-water from the north. Owing to these agencies, the equilibrium is probably continually disturbed, so that the heavier water of the north will slowly sink under the lighter water to the south. But owing to the effect of the Earth's rotation this movement will naturally also have a tendency to create an easterly flow of the latter water, while the southwards sinking heavier water will be deflected towards the west.

According to several previous observations, a current with Atlantic water should be flowing westwards along the southeastern and southern coast of Iceland.

There are only slight indications of such a current to be found in our Section II.

The deep depression of the isopycnals of 27.30, 27.40, and 27.50, between Stations 16 and 17, may, however, be due to such a current flowing along the slope of the Faeroe-Iceland Ridge, and then westwards along the slope of the Icelandic submerged shelf; but this is doubtful as it seems to be too far from the slope, and the current is very narrow in our section.

It is a strange fact that in most Danish vertical sections, across the shelf south of Iceland, of 1903 and 1904 [Nielsen, 1904, 1907], there are no indications of such a westerly current, as the isopycnals slope from the shelf seawards. Only in Section I of July 11 and 12, 1904 [Nielsen, 1907, Pl. II], the equilines slope gently from Station 66 towards Station 67 on the slope off the south coast of Iceland. It seems thus to be doubtful whether there is any well developed westerly flow along the slope off the southern coast of Iceland.

A very conspicuous feature of our Section II, is the steep inclination of all equilines along the slope from the platform south-east of Iceland towards the depths of the Atlantic. The cold heavy water, with low salinities (between 34.7 and 34.8‰), forming the bottom-layers over this western part of the Faeroe-Iceland Ridge comes from the north, with the East Icelandic Arctic Current, and sinks down the southern slope of this ridge into the Atlantic where it gradually intermixes with the bottom-water of the latter [cf. Nansen, 1912]. The

sinking movement of this water must be comparatively rapid, to judge from the small distances between the sloping isopycnals, and from the remarkably great differences in temperature, salinity, and density at the same levels (*e. g.* at 300 and 400 metres), at such short horizontal distances as between Stations 18 and 19. These great differences contrast strikingly with the great uniformity at similar levels in the sea farther south.

Owing to the deflecting effect of the Earth's rotation it is to be expected that this heavy water, sinking along the slope, will have a strong tendency to flow westwards along the slope south of Iceland.

As will be mentioned later, the water of the East Icelandic Arctic Current covering the submerged platform or shelf east of Iceland, was evidently unusually cold in the summer of 1910, and the current may possibly have been particularly strong that year. It is therefore possible that the quantity of cold heavy water sinking down the southern slope of the ridge, at our Stations 19 and 18, was greater that summer than usual, and it seems probable that the quantity of this arctic water flowing over the ridge into the Atlantic, may vary from one year to another.

X. Annual Variations in the Temperature of the Sea south and west of Iceland, and the Winter Temperature of south-western Iceland.

In the years 1895, 1896, 1903, 1904, and 1905 serial temperature observations were taken by the Danes (during the Ingolf Expedition 1895 and 1896, and during the cruises of the Thor 1903, 1904, and 1905) at a great number of stations in the sea south of Iceland¹). By a comparison of the observations at those stations which are approximately in the same localities, and also near the localities of our Frithjof Stations of Section II, of 1910, it is possible to form some idea of the variations in the temperature of the sea in this region in the years mentioned.

Figs. 39—44 give the temperature curves of 26 stations. One station (the Ingolf Station I 7) is from 1895, ten stations (the Ingolf Stations I 47—I 50, I 52, I 53, I 55, I 63—I 65) are from 1896, three

¹) The observations of these years are described by M. Knudsen [1899] and J. N. Nielsen [1904, 1905, 1907].

Irminger Current was warmest in 1896, less warm in 1895, 1904, and 1903.

There are consequently similar variations as in the sea south of Iceland, but the conclusions are here still less reliable, because the sea is shallower, and the frequent variations in depth may have a great influence upon the temperature, even at short distances.

Fig. 40. Vertical Temperature Curves of the Ingolf Stations I 47 of May 12, 1896, in $61^{\circ}32'N$, $13^{\circ}40'W$, I 48 of May 12, 1896, in $61^{\circ}32'N$, $15^{\circ}11'W$, and I 49 of May 13, 1896, in $62^{\circ}7'N$, $15^{\circ}7'W$; of the Thor Station T 39 of May 23, 1904 in $62^{\circ}17'N$, $14^{\circ}18'W$; and of the Frithjof Stations F 15 and F 16 (see Table).

By measuring with a planimeter the area between the different curves of Figs. 39 to 44 at depths between 200 and 800 metres, and giving due consideration to the differences in the positions of the stations, it is possible to obtain some estimation of the magnitude of the variations in the temperature of the sea in the different years. Let us assume that in 1904 the temperature of the sea was normal. By the above method I have then found the following anomalies of the

temperature at depths between 200 and 800 metres in the sea south of Iceland:

Year	1895	1896	1903	1904	1905	1910
Anomaly of Temp. ° C.	0.17(?)	0.3	-0.08	0.0	-0.06(?)	-0.28

Fig. 41. Vertical Temperature Curves of the Ingolf Stations I 50 of May 13, 1896, in $62^{\circ}43'N$, $15^{\circ}7'W$, and I 53 of May 16, 1896, in $63^{\circ}15'N$, $15^{\circ}7'W$; of the Thor Stations T 26 of May 31, 1903, in $63^{\circ}15'N$, $14^{\circ}20'W$, and T 40 of May 24, 1904, in $62^{\circ}47'N$ $15^{\circ}3'W$; and of the Frithjof Stations F 16 and F 17 (see Table).

Fig. 42. Vertical Temperature Curves of the Ingolf Station I 52 of May 15, 1896, in $63^{\circ}57'N$, $13^{\circ}32'W$; of the Thor Station T 120 of August 27, 1905, in $63^{\circ}42'N$, $13^{\circ}2'W$; and of the Frithjof Stations F 17 and F 18 (see Table).

Fig. 43. Vertical Temperature Curves of the Ingolf Stations I 7 of May 16, 1895 $63^{\circ} 13' \text{ N}$, $15^{\circ} 41' \text{ W}$, I 53 of May 16, 1896, in $63^{\circ} 15' \text{ N}$, $15^{\circ} 7' \text{ W}$, and I 55 of May 19, 1896 in $63^{\circ} 33' \text{ N}$, $15^{\circ} 2' \text{ W}$; of the Thor Stations T 41 and T 42 of May 24, 1904, in $63^{\circ} 14' \text{ N}$, $15^{\circ} 36' \text{ W}$, and $63^{\circ} 22' \text{ N}$, $15^{\circ} 52' \text{ W}$.

Fig. 44. Vertical Temperature Curves of the Ingolf Stations I 63 and I 64 of June 1, 1896, in $62^{\circ} 40' \text{ N}$, $19^{\circ} 5' \text{ W}$, and $62^{\circ} 6' \text{ N}$, $19^{\circ} 0' \text{ W}$; of the Thor Stations T 51 of July 13, 1903, in $62^{\circ} 11' \text{ N}$, $19^{\circ} 36' \text{ W}$, T 52 of July 14, 1903, in $62^{\circ} 35' \text{ N}$, $14^{\circ} 48' \text{ W}$, and T 66 of July 11, 1904, $62^{\circ} 45' \text{ N}$, $18^{\circ} 40' \text{ W}$.

But these values are of course very uncertain, as the material of observations on which the estimate is based, is much too inadequate.

The variations in the temperature of the sea south and west of Iceland, must naturally have some effect upon the climate of this island, particularly the winter temperature of its south and west coast.

Fig. 45. Vertical Temperature Curves of the Ingolf Stations I 89 (in $64^{\circ} 45' N$, $27^{\circ} 20' W$), I 90 ($64^{\circ} 45' N$, $29^{\circ} 6' W$), and I 96 (in $65^{\circ} 24' N$, $29^{\circ} 0' W$), of June 24 and 27, 1896; of the Thor Stations T 34 of June 12, 1903, in $65^{\circ} 28' N$, $28^{\circ} 31' W$, and T 58 of June 19, 1904, in $65^{\circ} 0' N$, $28^{\circ} 10' W$.

Fig. 46. Vertical Temperature Curves of the Ingolf Stations I 9 (in $64^{\circ} 18' N$, $27^{\circ} 0' W$), I 10 (in $64^{\circ} 24' N$, $28^{\circ} 50' W$), of May 20, 1895, and I 90 (in $64^{\circ} 45' N$, $29^{\circ} 6' W$) of June 24, 1896; of the Thor Stations T 32 (in $64^{\circ} 14' N$, $27^{\circ} 30' W$) and T 33 (in $64^{\circ} 14' N$, $28^{\circ} 31' W$) of June 11 and 12, 1903.

At the meteorological station at Stykkisholm (in $65^{\circ} 5' N$, $22^{\circ} 46' W$) the mean temperatures for the six months November to April were:

Mean temperature of November to April at Stykkisholm.

Winter	1894-95	1895-96	1896-97	1902-3	1903-4	1904-5	1905-6	1909-10	1910-11
Temp. °C.	-0.45	-0.50	-0.17	-1.02	-1.02	-1.02	-0.40	-1.70	-1.00

If we assume that the heat of the sea water observed has been the chief factor in determining the air temperature of the preceding winter and that the sea water tested in the various springs and summers has to a great extent been replaced by new water with a different temperature before the following winter, the variations in the mean winter temperatures of the atmosphere of western Iceland agree fairly well with the variations in the temperature of the sea, the

Fig. 47. Vertical Temperature Curves of the Ingolf Stations I 16 (in $65^{\circ} 43' N$, $26^{\circ} 58' W$) of June 5, 1895, I 97 (in $65^{\circ} 28' N$, $27^{\circ} 39' W$) and I 98 (in $65^{\circ} 38' N$, $26^{\circ} 27' W$), of June 28, 1896; of the Thor Stations T 36 (in $65^{\circ} 45' N$, $26^{\circ} 3' W$) and T 37 (in $65^{\circ} 38' N$, $25^{\circ} 38' W$) of June 13, 1903, T 57 (in $65^{\circ} 50' N$, $26^{\circ} 53' W$) and T 60 (in $65^{\circ} 27' N$, $27^{\circ} 10' W$) of June 18 and 21, 1904.

Fig. 48.

- Curve I. Anomalies of the Temperature of the sea south of Iceland, at depths between 200 and 800 metres.
- Curve II. Mean Winter Temperature (November—April) at Stykkisholm.
- Curve III. Mean Temperatures of each two succeeding winters at Stykkisholm.

highest temperatures (-0.45° and $-0.50^{\circ} C.$) being in the winters 1894—95 and 1895—96, and the lowest in the winter 1909—10, while the temperatures of the winter 1902—3, 1903—4, and 1904—5 were between these values.

If we assume that the heat of the sea water observed has to some extent influenced the air temperature of the preceding winter as well as that of the following winter, we also find an agreement in the variations of the sea temperature. The mean temperatures of each two winters would then be:

Winters	1894—96	1895—97	1902—4	1903—5	1904—6	1909—11
Temp. ° C.	— 0.47	— 0.34	— 1.02	— 1.02	— 0.71	— 1.3

The curves of Fig. 48 illustrate the apparent agreement between the variations in the temperature of the sea (Curve I) and the variations in the winter temperature at Stykkisholm (Curves II and III).

But, as pointed out above, the computed values of the variations in the temperature of the sea are very uncertain.

It should be noticed that they do not agree very well with the variations in the winter temperature at the Vestmanna Islands on the south coast of Iceland, and still less with those at Berufjord and Papey on the south-eastern coast of Iceland, while the agreement with the variations in the winter temperature at the meteorological stations in the southwestern and western part of Iceland (*e. g.* Örebrokke, Storanupr, Reykjavik, Gilsbakki) is on the whole much better.

XI. The East Icelandic Arctic Current.

A comparison between our observations east of Iceland with those taken by the Norwegians in 1902 and by the Danes in the same region in 1903, 1904, and 1905 shows that the bottom strata covering the submerged shelf and the slope east of Iceland was in July 1910 considerably colder than in any other spring or summer from which we have observations. Our section between Stations 22 and 25 is very nearly the same as the Danish Section between Stations Da 19 and Da 17, as it is only about eight miles farther north. Observations were taken at these Danish stations in May and August in the two years 1903 and 1904, in May 1905, and at some of the stations in July 1905. Some observations were also taken in August 1902 at three Norwegian stations, Station N 94, in 64° 58' N, 11° 32' W, Station N 95 A, in 64° 56' N, 11° 45' W, and Station N 95, in 64° 56' N, 11° 48' W. But it was only in May 1903 that a temperature below freezing point (—0.12 C.) was observed in the water covering the shelf east of Iceland, and this was only at 200 metres (7 metres above the bottom) at one station (Station 17) near the edge of the shelf. In our section there was a bottom layer with temperatures below 0° C. (— 0.1°, — 0.3° and — 0.4° C.) at two stations (Stations 23 and 24, and also between Station 22 and 23), and even at a depth of 165 metres below the surface, or 45 metres above the bottom (at Station 23).

Taking all observations made at depths between 95 metres and the bottom at the Norwegians Stations 94—95, of August, 1902, at the Danish Stations 17 and 18 (Station 19 is too near the coast) in 1903—1905, and at our Stations 22—24 in 1910 we find the following mean values of temperature and salinity:

	August 1902	May 1903	August 1903	May 1904	August 1904	May 1905	July 1910
Temp. ° C. . .	1.18	0.60	0.64	0.69	1.03	0.53	0.23
S ‰	34.72	34.77	34.67	34.69	34.81	34.85	34.75

The temperature of the water at these depths greater than 95 metres is evidently much raised by the heat wave from above in the course of the summer, as is shown by the mean temperatures of August 1902 and 1904. In spite of this fact, the mean temperature of July 1910 (0.23°C.) is considerably lower than the mean temperatures of May 1903, 1904, and 1905. But then it should be considered that the stations of 1910 were some eight miles farther north than those of the earlier years, although this cannot be sufficient to account for the difference in temperature.

The Danish observations in May 1903—1905, prove that the cooling of the sea surface during the winter creates a very active vertical circulation in the water over the shelf, so that at the end of the winter the temperature and salinity become nearly uniform between the surface and the bottom at 200 metres or deeper. It might then seem possible that the low temperature of the deep water at our Stations 22—24, in July 1910, was due to an excessive cooling during a comparatively cold winter. The winter and spring of 1910 was, as a matter of fact, comparatively cold on the east coast of Iceland, but hardly to such an extent that it can explain the occurrence of the cold water. The mean temperatures for November to April were in Beru Fjord (in $64^{\circ}40' \text{N}$, $14^{\circ}15' \text{W}$) and in Papey (in $64^{\circ}30' \text{N}$, $14^{\circ}13' \text{W}$) as follows:

Winter	1901—2	1902—3	1903—4	1904—5	1909—10
Beru Fjord. Temperature ° C. . .	— 1.27	0.33	0.62	— 0.53	— 0.45
Papey. Temperature ° C.	— 1.42	0.45	0.78	— 0.33	— 0.47

The coldest winter was, on the east coast, as over the whole of Iceland, the winter 1901—1902, but judging from the temperatures observed in August 1902 the water covering the shelf east of Iceland

was that year comparatively warm. The variations in other years do not agree very well either.

It seems more probable that the observed variations in the temperature of the water over the shelf and slope east of Iceland are chiefly caused by variations in the currents, partly the Icelandic Coast Current and partly the East Icelandic Arctic Current; sometimes also, warmer water coming from the south may possibly be of some importance. In years when the coast current is comparatively well developed, the arctic current will be kept off further from the coast and the water over the shelf will probably be warmer than in other years. The water of the coast current in the spring will naturally be influenced by variations in the precipitation over eastern and northern Iceland during the preceding years or the preceding winters, and also by the amount of melting of the snow on land during the spring.

The precipitation was at Berufjord in millimetres:

Years	1901	1902	1903	1904 ¹⁾
Precipitation in mm	1470	1167	1354	1447

The mean temperatures of the months March, April, and May were at Berufjord:

	1902	1903	1904	1905	1910
Temperature ° C.	0.43	1.23	2.80	2.4	2.0

The variations in these values do not agree with the variations in the observed temperatures of the water over the shelf. And besides if the latter variations were due to variations in the coast current as mentioned, we should expect to find variations in the salinity of the water over the shelf in the opposite direction, *i. e.* a rise in the temperature should be combined with a fall in the salinity and *vice versa*, but the salinities observed (see p. 107) hardly indicate variations of this kind.

It might then seem more probable that the variations in the temperature of the deep water over the shelf and the slope, off the east coast of Iceland, are chiefly due to variations in the East Icelandic Arctic Current. This is also confirmed by the shapes of the isopycnals in our section as well as in sections from previous years [cf. Nielsen 1904;

¹⁾ The amount of precipitation in 1909 was not available.

Helland-Hansen and Nansen, 1909, Pls. XXI A, XXII], which indicate that the water over the shelf east of Iceland moves southwards. The volume and velocity as well as the temperature of the East Icelandic Arctic Current may vary in different years, which will cause variations in the bank water east of Iceland.

Our Section III (Pl. XIV) shows that the water with temperature below 0°C . reached on the whole to very high levels east of Iceland in July 1910.

The isotherm of 0°C . rises to a depth of about 150 metres at Station 23, thence it slopes westwards to 400 metres at Station 28; but then it keeps very nearly that level farther westwards beyond Station 34. It has not such a high position, in similar sections from previous years, where it sinks to depths of 500 and 600 metres [cf. Helland-Hansen and Nansen, 1909, Pls. XXI A, XXII], but the explanation may to a great extent be that the section of 1910 was nearer to the cold axis of this sea, where the cold deep-water approaches nearest to the surface.

XII. The Waters of the Faeroe-Shetland Channel.

In Section IV (Pls. XVI and XVII), from Station 35 towards the Faeroes, all equilines rise in a very conspicuous manner to comparatively high levels at Station 37, and have exceptionally steep slopes towards Station 38. As the differences between the levels of water with equal density at both stations are 200 and 300 metres, it does not seem possible that these peculiar shapes of the equilines could be due to vertical movements caused by intermediate waves which have lifted the water-strata at Station 37, and depressed them at Station 38.

The steep slopes of the isopycnals (Pl. XVII) seem therefore to be chiefly due to rapid horizontal movements of the water. The water between Stations 37 and 38, with salinities between 35.20 and 34.84‰, must have flowed south-eastwards along the slope off the Faeroe-shelf, at all depths between the surface and, say, 600 metres, with a comparatively great velocity; while between Stations 37 and 36 the water possibly flowed in the opposite direction though with much less velocity. Between Stations 36 and 35 there may have been a slower south-eastward movement.

This agrees remarkably well with the movements that have been found to the north-west, in sections across the current along the Faeroe-

Iceland Ridge. By a combination of the Danish observations of 1903 and 1904 with the Norwegian ones of the same years, Helland-Hansen and I have drawn sections northwards from the Faeroes, as well as in a north-easterly direction across the Faeroe-Iceland Ridge, where the equilines, and particularly the isopycnals, have similar shapes to those in this section, although they do not slope so steeply. Our sections from May 1903, and May 1904, may be especially mentioned [see Helland-Hansen and Nansen, 1909, Pl. XXIB, Figs. 3, 4, and 6, Pl. XXIV B, Figs. 3 and 4]. In the sea north-east of Iceland there are also similar movements as we have pointed out [cf. 1909, p. 296, Figs. 99 and 101]. But in none of these sections from earlier years are there indications of movements along the slope with so great velocities as in our present section of July 1910, north-eastwards from the Faeroes. This section thus proves that the Atlantic water coming from the west, north of the Faeroe Platform, may run with a considerable velocity along the slope south-eastwards towards the Faeroe-Shetland Channel, as Helland-Hansen first pointed out [1905, see also Helland-Hansen and Nansen, 1909, p. 139 *et seq.*].

If we assume that there was lateral equilibrium in Section IV (which may be doubtful) and that the water had no motion at the depth of 600 metres, we may compute the velocities of the currents at the different depths between the stations by means of our above method (see p. 49). Let us assume that the south-eastward motion of the water between stations 37 and 38, and between 35 and 36, and the north-westward motion between stations 36 and 37 were directed perpendicularly to the direction of the section; we find then the following velocities in centimetres per second:

Depth in metres	Surface	100	200	300	400	Mean between 0 and 600
Velocity between Stations 35—36	7.0	6.1	4.3	2.5	1.1	3.0
" " " 36—37	11.5	10.4	6.0	2.9	1.2	4.4
" " " 37—38	34.4	33.4	23.7	11.8	3.8	15.0

According to the thus computed values of the mean velocity of the current between the surface and 600 metres (=15 cm/sec) the volume of water carried south-eastwards between stations 37 and 38 should be about 2.1 million cubic metres per second.

In the same manner we find that about 0.63 million cubic metres of water was carried north-westwards per second between stations 36 and 37, and 0.49 million south-eastwards between stations 35 and 36.

Section IV also demonstrates clearly how the rapid movement of a current running along a slope of the sea-bottom, is frequently limited to a very narrow belt over the slope near the edge of the shelf, while the water has comparatively slow motion on both sides of this narrow belt, in the deep sea outside as well as in the shallow water over the platform inside [cf. Helland-Hansen and Koefoed, 1909; Helland-Hansen and Nansen, 1909, p. 283 *et seq.*]. The features are very much the same as on the other side of the Faeroe-Shetland Channel where the Atlantic water runs north-eastwards into the Norwegian Sea as a very narrow current along the continental slope, while in the middle part of the channel rapid vortex movements occur.

The character of the Atlantic water running along the slope through our Section IV, into the Faeroe-Shetland Channel, is much the same as was found in the sections through the Danish Stations Da 2—Da 4, north of the Faeroes, in earlier years. The salinity is in our section perhaps somewhat lower, as might be expected, considering that the water has travelled some distance eastwards from the position of the Danish section and may have been intermixed with other water on the way.

Our Section IV proves the necessity of taking many stations at short intervals if one wishes to obtain a section giving a trustworthy representation of the conditions. The distance between the stations in Section IV is about 15 nautical miles (28 kilometres), while the distance between the Danish Stations Da 2, Da 3, and Da 4 north of the Faeroes [cf. the sections in Helland-Hansen and Nansen, 1909, Pl. XXIB, Fig. 4; Pl. XXII, Fig. 4, Pl. XXIVB, Fig. 3] is exactly double, *viz.*: about 30 nautical miles or 56 kilometres. If in Section IV the observations at Station 37 had not been taken, we would have got an entirely different section, and the course of the equilines would have been very similar to what we find in the sections through the Danish Stations to the north-east. Or if the observations at Stations 36 and 38 had been left out, the section would also have been very different.

Section V (Pls. XVI and XVII) across the Faeroe-Shetland Channel is of much interest. It exhibits more undulations or „waves“ of all equilines, and more regularly developed, than in any previous section of the channel.¹⁾ This cannot be explained merely by the fact that there are more stations, and at closer intervals, than in the other

¹⁾ See Helland-Hansen [1905], Robertson [1907] and the international Bull. Trimestriel etc. (Copenhagen) for later years.

sections; though if so many stations had not been taken, the „waves“ would not have been seen so well developed in the section. In the

Fig. 49. The Southern Scottish Section across the Faeroe-Shetland Channel, of August 8—10, 1910, along the line M in Fig. 1 (see Bull. Hydrogr. 1910—1911, Copenhagen). Scales and Shading same as in Figs. 4—12.

four sections across the Faeroe-Shetland Channel, taken about three weeks later by the Murray Hjort Expedition [1912, p. 281, 282], and the Scottish oceanographers (see Figs. 49, 50), the „waves“ are fewer in number, have very different shapes, and are less developed. The southern section of the Murray Hjort

Fig. 50. The Northern Scottish Section across the Faeroe-Shetland Channel of August 12—15, 1910, along the line N in Fig. 1 (see Bull. Hydrogr. 1910—11, Copenhagen). Scales and Shading same as in Figs. 4—12.

Expedition shows perhaps most resemblance to our section in this respect. In the southern Scottish section across the channel of May 1904, the equilines have shapes rather similar to those of our section, with even steeper and more abrupt slopes, but there is only one „wave“ [see Robertson, 1907, Pl. II; Helland-Hansen and Nansen, 1909, Pl. XXIV B, Fig. 1]. It seems, however, probable that if there had been a greater number of stations at shorter intervals, many of the Scottish sections across the Faeroe-Shetland Channel would also have exhibited more „waves“. We still know nothing definitely as to the real nature of these „waves“, whether they solely indicate horizontal movements of the water, more or less vortex-movements, or whether they also to some extent are due to vertical movements of the water, caused by intermediate waves, or boundary waves [cf. Helland-Hansen and Nansen, 1909, p. 89 *et seq.*]. It seems very probable that such intermediate waves might easily be formed in this channel into which the Atlantic water runs over the threshold of the Wyville Thomson Ridge [see 1909, p. 92], and we do not yet know what the size of such waves may be. But, on the other hand, the „waves“ observed in the various sections taken across the channel, are so great that they cannot possibly be explained merely as intermediate waves, their heights rising to 200 and 250 metres. And then it is also noteworthy that there are certain features connected with these „waves“ which are much the same in all sections. I may especially mention the steep inclination of all equilines towards the continental slope on the Shetland side of the channel, in all sections where the distances between the stations are not too great.

A general conclusion drawn from the many sections across the Faeroe-Shetland Channel is, however, that there are continually very great changes in the position of the waters in this channel, whatever the causes of these changes may be.

After Helland-Hansen and I [1909] had come to the conclusion that great subsurface boundary waves probably occur in the sea, and that the „waves“ seen in the many vertical sections of the Norwegian Sea may be due, partly to such boundary waves, partly to horizontal vortex-movements, I attempted to study the problem in the sea on the continental slope off Stad, on the west coast of Norway, in the summer of 1909, and in one case the observations were continued for 36 hours at different depths at the same station marked by an anchored buoy. At our instigation it was also decided at the meeting of the International Council for the Study of the Sea, at Copenhagen, in

August 1909, that special investigations for the study of these phenomena should be organized in the following year, if possible by a co-operation of the Scottish, Danish, and Norwegian oceanographers.

The following year such investigations were carried out in the Faeroe-Shetland Channel.

Between August 8 and 15, 1910, four sections were taken across this channel, by the Scottish and the Norwegian oceanographers; some short distance south of our Section V of July 1910. Continuous observations at different depths were also carried on for 24 hours simultaneously at one Scottish and one Norwegian station [cf. Bull. Hydr., Copenhagen, for 1910—1911; Helland-Hansen, 1912, p. 279 *et seq.*]. Similar series of observations were also made in the Faeroe-Shetland Channel by the Danes in May 1910 [M. Knudsen, 1911] and by the Scottish oceanographers in May 1911 [Bull. Hydr., Copenhagen, 1910—1911].

In 1912 I also made investigations of this kind in the drift ice north-west of Spitzbergen.

The results of these investigations are that vertical oscillations of the intermediate strata (of the kind I observed during the drift of the Fram in 1893—1896) do frequently occur in the sea, and that at least some of these oscillations have some connection with the tidal phenomena as was assumed by Helland-Hansen and myself. But the height of the oscillations in the above cases did not as a rule exceed 30 or 40 metres; and did not approach the size of the waves in our Section V by a very long way.

In Fig. 51 the observations at Stations 35—48 are introduced at their proper depths, and according to their date and hour (which are marked along the sea-surface) regardless of the distances between the stations. The isohalines and isotherms are then drawn in the same manner as in an ordinary vertical section. The upper and lower meridian passages of the moon are marked by rings and black discs at the foot of the figure.

The “waves” of the equilines have a remarkable resemblance to regular vertical oscillations, with periods similar to those of the tidal wave. The agreement is so perfect that it seems difficult to think that it is accidental. And moreover the observations were made on July 18th—20th, 1910, a few days before full moon which occurred on July 22nd, 1910, at which period the tidal wave might be expected to be fairly well developed.

Nevertheless it is hardly possible that the "waves" of Section V, 200 metres high or even more, are merely due to tidal oscillations. It is not improbable that the summits of subsurface tidal waves have happened to pass the regions of our Stations 37, 41, and 45, at the time of our observations, which at these three stations happened to

Fig. 51. The Observations of Temperature and Salinity at different depths (in metres) at Stations 35—48, introduced in a section according to the intervals of time between the observations, and regardless of the distances between the stations. The hours from 6 p. m., on July 18, to 8 a. m. on July 20, 1910, are marked along the sea-surface. A ring (at the foot of the Figure) denotes upper meridian passage of the moon, a black disc lower meridian passage.

be a few hours after the passages of the moon, when they might be expected to occur (cf. the Danish observations of May 1910 [Knudsen, 1911]).

In this manner the height of the "waves" of Sections IV and V may have been increased; but these "waves" cannot have been merely tidal phenomena, as we know no instances of waves of such dimensions being thus formed. Moreover, at Station 41 was the summit of

a „subsurface wave”, but on the surface the salinity was at the time unusually low (34.98‰), and this cannot be explained by any vertical oscillation, but easily *e. g.* by horizontal vortex-movements having carried water with low salinity to that locality. In the region of Stations 42—44 there was a body of water with high salinity (above 35.20‰) near the surface. This agrees well with the occurrence of the trough of a “wave” at Station 43, but the occurrence of this saline surface layer cannot easily be explained by any vertical oscillatory movement.

What the “waves” of Section V actually represent, whether they are due to horizontal vortex-movements or other movements, is still somewhat difficult to decide, as the movements of the water in this region appear to be very complicated.

In order to attain to a more definite conception as to the possible relation between the tidal wave and the “waves” of the equilines in the sections, I have examined 14 Scottish sections across the Faeroe-Shetland Channel, taken from August 1902 to June 1905 (see Helland-Hansen 1905; Robertson 1905, 1907; Bull. de Résult. etc. Copenhagen). In eight sections there were well developed “waves”, and in most cases the observations at the summits of the “waves” were taken between two and three hours after the meridian passages of the moon, while the observations coinciding with the deepest troughs of the waves were taken as a rule between 8 and 10 hours after the passages of the moon.

In six sections the “waves” were not well developed, although the four sections were taken at the full of the moon or shortly before; but it has to be admitted that in most cases the observations of these sections were not taken at hours (after the passages of the moon) when the summits or the troughs of the tidal waves might be expected to have passed the stations.

In a few cases, however, troughs of waves were observed at times when there should have been crests if the waves had been tidal waves. At Stations Sc. 13 on December 10, 1902, and Sc. 19B on June 26, 1905, there were deep troughs, though the observations were taken about 2 hours and 3 hours after the passages of the moon. But these stations were on the continental slope on the east side of the channel, where the strata may always be expected to be much depressed owing to the north-eastward current and the deflecting force due to the Earth's rotation.

In the southern Scottish section across the channel, of August 1904, there was, however, a distinct trough of a wave at station Sc. 19B, near the middle of the channel, although the observations were taken between 2 hours before and 2 hours after the passages of the moon, when one might expect to have been nearer the crest of the tidal wave.

It is not easy in this manner to arrive at any definite conclusion as to the relation between the "waves" of the sections and the tidal wave, and a more thorough study of this important problem has to be postponed to a later occasion. The general impression received by our investigations above, is none the less that the tidal wave has some influence upon the "waves" observed in the sections, the greatest difference in height between the crests and the troughs of the latter waves being observed when the observations coincide with the tide-period. It has, however, to be kept in view that, the question is much complicated by the horizontal vortex-motions and other motions of the water in the Faeroe-Shetland Channel.

It is to be hoped that when the observations of the four simultaneous Scottish and Norwegian Sections across the channel, of August 8—15, 1910, have been published and discussed, we shall know more about the nature of these phenomena. Helland-Hansen and I have already compared the many observations of 1910 and other years, we have found that the question is an extremely difficult one; and our impression is that there are often very active vortex-movements or similar movements in the channel, by which detached bodies of water with different salinities may be formed.

The steep inclination of the isopycnals of 27.60, 27.70, and 27.80 from Station 41 towards the slope off the Faeroe Platform indicates that the Atlantic water running south-eastwards between Stations 37 and 38 of Section IV, continues to some extent its course along the slope into the Faeroe-Shetland Channel. As Section V has a westerly direction, it probably crosses this current obliquely, and this may to some extent be the reason why the inclination of the isopycnals are less steep in this section than in Section IV. The isopycnals of 27.50, 27.40 etc. above 100 metres have a nearly horizontal course westwards from Station 41 (see Pl. XVII). This may indicate either that the water of these top-layers does not run south-eastwards with a greater velocity than the underlying strata, below 200 metres, or also that the direction of the surface current has been nearer to the direction of the section.

Provided that there was lateral equilibrium in the section between Stations 40 and 41, that the direction of the current formed an angle of 60° to 70° with the direction of the section, and that the water had no motion near the bottom, at 450 metres, at station 41, we find by the method described above (p. 49) the following velocities in centimetres per second in the current between stations 40 and 41:

Depth in metres	Surface	100	200	250	300	400	Mean between 0 and 450
Velocity in cm/sec.	12.0	14.1	12.1	9.7	6.2	1.1	8.7

From a rough calculation we thus find that about 0.96 million cubic metres of water should be carried southwards between station 40 and 41. This is less than half the volume of water carried south-eastwards along the slope between stations 37 and 38, to the north-west of stations 40 and 41. If this be correct, we must conclude that a great deal of the water flowing south-eastwards between stations 37 and 38, is carried away in some easterly direction before it reaches stations 40 and 41.

On the Shetland side of the channel the water between the surface and 700 metres, or deeper, was obviously running with considerable velocities north-eastwards along the continental slope between Stations 45 and 46. The water over the continental shelf at Station 48 has evidently had very little motion, as is generally the case over the shelves, and we find here as usual that the water near the bottom, at depths of 100 and 150 metres, is heavier than the water at the same levels over the continental slope. It seems probable that this heavier water is the winter-water still remaining near the bottom on the shelf.

Provided that there was lateral equilibrium in the section between stations 44 and 47, that the mean direction of the north-eastward current has formed an angle of about 70° with the direction of the section, and that the water had no motion at 700 metres (which is very doubtful), we find the following horizontal velocities between stations 46 and 47:

Depth in metres	Surface	100	200	300	400	500	Mean between 0—700
Velocity in cm/sec.	27.4	23.6	22.0	17.8	9.0	3.1	12.7

Between Stations 46 and 47 the velocities of the current were slower, and between stations 44 and 45 there was very little northward motion.

From a rough calculation I have found that the north-eastward current along the continental slope between stations 44 and 47 carried away 4 million cubic metres of water per second. This agrees remarkably well with the volumes of the same current computed for August 1902 (4 million cub. m./sec.) and for May and June 1904 (4.5 million cub. m./sec.) [see Helland-Hausen, 1905, p. 9; Helland-Hansen and Nansen, 1909, p. 169].

It has to be kept in view that all the above computations of the velocities of the currents, and of the volumes of water carried by them, are based upon the supposition that there was lateral equilibrium in the sections, and that consequently the slopes of the isopycnals were exclusively due to the horizontal motion of the water and the deflecting force caused by the Earth's rotation. But this supposition is hardly correct for, as was shown above (p. 117); the "waves" or undulations of the equilines in the sections are probably also to some extent influenced by vertical motions (oscillations) of the water strata which may either increase or decrease the apparent gradients of the isopycnals in the sections. On the other hand we have supposed that the water had no motion at the depth of 600 or 700 metres. This may be very doubtful. If the water at this depth was flowing in the same direction as the overlying strata the computed velocities of the current would have to be increased accordingly.

In the central part of the channel there has probably been a vortex-movement, such as has also been found in earlier years. The water between Stations 44 and 43 has probably been moving rapidly in a southerly direction at all depths between the surface and 500 or 600 metres, while between Stations 43 and 41 the water has been moving in an opposite direction.

An interesting feature in Section V is the occurrence of a great body of water with salinities between 34.90 and 34.86‰, which was rarely observed in the Scottish sections across the channel further south. This is evidently the Arctic water of what Helland-Hansen and I [1909] have called the "tongue".

XIII. The supposed Bank north-east of the Faeroes.

A sounding of 373 metres (204 fathoms) was recorded at Station 38 of the Norwegian North Atlantic Expedition, of July 17, 1876, in 63° 1' N. Lat., 3° 58' W. Long. [cf. Mohn, 1887, p. 45, Pl. I].

This solitary sounding seemed to indicate the existence of a bank far out in the deep sea north-east of the Faeroes. But as the existence of this bank was never indicated by any other soundings, and as a number of soundings taken by the Michael Sars along the northeastern edge of the Faeroe submerged shelf (*i. e.* between the Faeroes and this supposed bank to the north-east) indicated a regular steep slope from the edge of the shelf towards the oceanic deep (at least as deep as beyond 600 metres [cf. Nansen, 1904, Pl. XXIII]), I always considered the existence of this bank somewhat doubtful, but having had no opportunity of examining it, I considered it most correct to draw the bank in the bathymetrical charts [see Nansen, 1904, Pls. I and XXIII, cf. also Helland-Hansen and Nansen, 1909, Pl. I].

In order to get more trustworthy information about the bathymetrical features in this important region where the waters of the East Icelandic Arctic Current and the Atlantic Current, running north of the Faeroes, enter the Faeroe-Shetland Channel, the homeward course of the Frithjof was directed to the locality of Stations 38 of the Norwegian North Atlantic Expedition, and from that place towards the Faeroes. The following soundings were taken:

Station	N. Lat.	W. Long.	Depth	
	62° 58'	4° 07'	1050 metres	no bottom
35	62° 56'	3° 43'	1240	no bottom
36	62° 48'	4° 10'	1300	
37	62° 40'	4° 35'	780	
38	62° 33'	5° 01'	500	
39	62° 24.5'	5° 27'	207	"

These soundings seem to prove that the bank does not exist, at least not with the extent and in the locality hitherto assumed. The first sounding above should have been nearly in the same locality as the sounding of 1876, but it has not been introduced in the chart Fig. 52. The latitudes and longitudes of our soundings may be considered as very trustworthy, as we had bearings of the Faeroes at Station 39, which agreed well with our dead reckoning and our astronomical observations.

I have discussed the matter with Prof. Mohn, who has carefully re-examined all data regarding the sounding at Station 38 of July 17, 1876, but without finding any indications of a mistake, as to depth or locality. The position was computed by dead reckoning, but as they had left the Faeroes the day before, the weather being good, and had

taken only two stations (Stations 36 and 37) in the Faeroe-Shetland Channel on the way, there does not seem to be much probability of any great mistake in this respect.

Fig. 52. Bathymetrical Chart of the Sea north and north-east of the Faeroes. Depths in metres. Soundings in upright figures by the Frithjof 1910.

If, therefore, we have to accept the depth and locality of Station 38, 1876, as approximately correct, the only explanation seems to be that the sounding has happened to hit some isolated small cone rising above the bottom of the deep sea somewhere to the north of our soundings.

Table,

giving the Observations taken on board the Frithjof, July 6th—21st, 1910.

- 1st Column. Observation-Station's Number.
- 2nd Column. Date and Hour (local time) of the Observations.
- 3rd Column. North Latitude.
- 4th Column. Longitude West of Greenwich. The last nine surface-observations taken on July 20—21, 1910, were taken East of the Greenwich Meridian.
- 5th Column. Depth in Metres. A line under the number indicates bottom.
- 6th Column. Instrument used. **B** = Bucket used for surface-water: the temperature was taken with an ordinary thermometer inserted in the water of the bucket, the observations were made by the Cadets. **A** = the Automatic Insulating Water-Bottle. **PN₁** = the Pettersson-Nansen Insulating Water-Bottle with the Nansen Thermometer No. P. T. R. 37550. **PN₂** = the Pettersson-Nansen Water-

Bottle with the Richter Reversing Thermometer No. P. T. R. 37547. **RB** = the Reversing Stop-Cock Water-Bottle with the Richter reversing thermometer No. P. T. R. 37544. **I** = Stop-Cock Water-Bottle with the Richter reversing thermometer No. P. T. R. 37552. **II** = Stop-Cock Water-Bottle with the Richter reversing thermometer No. P. T. R. 37547.

7th Column, $t^{\circ}\text{C}$. The corrected Temperature (Centigrade) *in situ*.

8th Column, $S^{\circ}_{\text{‰}}$. Salinity per mille. An asterisk after the number indicates that several titrations were made of the water sample. i after the number indicates that the sample was examined with the Löwe Interferometer.

9th Column, σ_t . Density (i. e. $(S \frac{t}{\sigma} - 1) 1000$) at the temperature *in situ* when the pressure is reduced to one atmosphere.

Stat. No.	Date and Hour l. t.	N Lat.	W. Long.	Depth Metres	Water-bottle	$t^{\circ}\text{C}$.	$S^{\circ}_{\text{‰}}$	σ_t
1	July 1910							
	6, M	55° 28'	7° 00'	0	B	10.7	34.13	26.16
	2.00 a. m.	55° 32'	7° 25'	0	"	12.6	.81	.34
	.30 "			25	A	9.7	35.12	27.12
	.45 "			55	"	.0	.165	.27
	3.00 "			10	"	11.9	34.85	26.51
	4.00 "	55° 35'	7° 50'	0	B	.9	.65	.35
	5.05 "			19	A	12.3	35.11	.63
	.25 "			60	"	9.1	.29	27.35
	.35 "			48	"	.2	.29	.33
	6.00 "	55° 39'	8° 16'	0	B	12.8	.10	26.53
	7.50 "			28	A	11.2	.34	27.02
	8.00 "	55° 42'	8° 41'	0	B	12.9	.05	26.47
	.00 "			60	A	9.2	.33	27.36
	.08 "			9	"	12.7	.075	26.53
	.14 "			88	"	9.25	.32	27.35
	10.00 "	55° 46'	9° 07'	0	B	12.8	.10	26.53
	.55 "			28	A	9.5 ¹⁾	.38	27.35
	11.00 "			65	"	.4	.35	.35
	.10 "			120	"	.5?	.37	[.35]
	.26 "			160	"	.65?	.37	[.32]
	{ N	55° 48'	9° 25'	0	B	13.0	.22	26.58
	0.17 p. m.	" "	" "	200	A	9.4	.36	27.36
	.30 "	" "	" "	300	"	.4	.37	.37
	.50 "	" "	" "	400	"	.3	.35	.37
	1.30 "	" "	" "	600	PN ₁	.16	.35	.40
	2.16 "	" "	" "	750	PN ₁	8.96	.34	.42
	.00 "			0	B	13.3	.21	26.51
	4.00 "	55° 51'	9° 41'	0	"	.5	.35	.58
	.17 "			27	A	12.3	.37	.84
	.27 "			60	"	10.3	.36	27.20
	.37 "			114	"	9.7	.36	.30
	.50 "			215	"	.5	.37	.35
	{ 5.45 "	55° 53'	10° 00'	600	PN ₁	8.27	.255	.46
	6.00 "	" "	" "	0	B	13.2	.345	26.64
	.30 "	" "	" "	400	PN ₁	8.93	.34	27.42
	.55 "	" "	" "	400	"	.38	.31	.49
2.								

¹⁾ The journal has 7.5° C. which is probably an error for 9.5° C.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S ‰	σ_t
2a	July 1910							
	{ 6, 8.00 p. m.	55° 54'	10° 10'	0	B	13.2	35.30	26.60
	.17 "	" "	" "	1000	PN ₂	6.45 ¹⁾	.17*	27.66
	.57 "	" "	" "	1500	"	4.08 ²⁾	34.97 ^{*i}	.79
	10.00 "	55° 56'	10° 20'	0	B	13.23	35.32	26.61
	.00 "	" "	" "	10	A	13.0	.36	.69
	.10 "	" "	" "	39	"	12.2	.39	.87
	.27 "	" "	" "	95	"	9.8	.36	27.29
	.38 "	" "	" "	180	"	.4	.35	.35
	M	55° 59'	10° 42'	0	B	13.0	.26	26.61
	M	" "	" "	20	A	12.7	.29	.69
	7, 0.15 a. m.	" "	" "	35	"	.3	.30	.78
	.40 "	" "	" "	94	"	9.8	.37	27.29
	.55 "	" "	" "	150	"	.9 ²⁾	.35	.26?
	2.00 "	56° 02'	11° 03'	0	B	12.9	.29	26.65
	.10 "	" "	" "	20	A	.5	.29	.73
	.39 "	56° 03'	11° 10'	400	PN ₁	9.18	.35*	27.39
3	{ 3.09 "	" "	" "	600	"	8.70	.27*	.41
	.37 "	" "	" "	1000	RB	.26 ³⁾	.19 ^{*i}	.42?
	4.21 "	" "	" "	1500	"	4.13	.00 ^{*i}	.82
	.00 "	" "	" "	0	B	12.8	.28	26.67
	5.05 "	" "	" "	800?	RB	9.17?	.34*?	27.39?
	6.00 "	56° 05'	11° 18'	0	B	12.8	.29	26.67
	.00 "	" "	" "	20	A	.6	.29	.71
	6.07 "	" "	" "	40	"	12.0	.345	.88
	.21 "	" "	" "	62	"	9.7	.35	27.30
	.37 "	" "	" "	135	"	.5	.34	.32
	8.00 "	56° 08'	11° 38'	0	B	13.0	.33	26.67
	.00 "	" "	" "	16	A	12.4	.35	.80
	.35 "	" "	" "	20	"	11.8	.345	.91
	.40 "	" "	" "	47	"	10.7	.38	27.14
	.52 "	" "	" "	80	"	9.8	.38	.30
	9.10 "	" "	" "	140	"	.7	.36	.30
	10.00 "	56° 11'	12° 03'	0	B	13.3	.35	26.62
4	.03 "	" "	" "	20	A	12.1	.37	.88
	.15 "	" "	" "	49	"	10.3	.39	27.22
	.35 "	" "	" "	107	"	9.6	.41	.36?
	.57 "	" "	" "	210	"	.4 ⁴⁾	.37*	.37
	{ 11.30 "	56° 13'	12° 13'	402	"	.1	.35*	.40
	.37 "	" "	" "	600?	RB	.55?	.35*	.33?
	0.06 p. m.	" "	" "	1000	"	8.29	.23*	.45
	.28 "	" "	" "	1500	"	4.90	.04*	.75
	1.30 "	" "	" "	2000	"	5.41	.38*	.97
	N	" "	" "	0	B	13.4	.345	26.60
	2.00 p. m.	56° 13'	12° 13'	0	"	.9	.36	.50

¹⁾ The Nansen-Thermometer of the insulating water-bottle gave 6.41° C., not allowing for the adiabatic cooling.

²⁾ The Nansen-Thermometer of the insulating water-bottle gave 4.11° C. not allowing for the adiabatic cooling.

³⁾ The journal has 9.34 (9.3)° C. = 9.26° C. The 9.34 is probably an error for 8.34.

⁴⁾ The journal has 8.4° C., but this is evidently an error for 9.3° C.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water- bottle	t° C.	S‰	σ_t
5	July 1910							
	7, 4.00 p. m.	56° 17'	12° 38'	0	B	14.9	35.41	26.33
	.10 "			19	A	12.8	.39	.75
	.18 "			48	"	10.87	.385	27.12
	.25 "			105	"	10.1	.42	.28
	.35 "			150	"	9.7	.35	.30
	6.00 "	56° 23'	13° 03'	18	"	12.6	.35	26.76
	.07 "			45	"	11.1	.355	27.05
	.20 "			104	"	10.1	.35	.23
	.35 "			180	"	9.7	.37	.31
	7.00 "			0	B	13.8		
	.20 "	56° 27'	13° 19'	450	A	8.8	.34	.44
	.30 "	" "	" "	600	II	.40	.30	.48
	.30 "	" "	" "	1000	RB	6.51	.17 ^{*i}	.65
	8.14 "	" "	" "	1400	II	4.50	.01 ^{*i}	.78
	.14 "	" "	" "	1900	RB	.83	.31 ^{*i}	.98
	.55 "	" "	" "	202	A	9.2	.30	.34
	.00 "			0	B	13.6	[.08]?	[26.35]
	10.00 "	56° 29'	13° 30'	0	"	.4	.30	.56
	.05 "			21	A	12.4	.28	.75
	.11 "			49	"	10.2	.37	27.22
	.25 "			102	"	9.6	.36	.32
	.40 "			165	"	.7?	.345	.29?
	M	56° 34'	13° 52'	0	B	13.2	.28	26.59
6	8, 0.20 a. m.	" "	" "	600	II	8.33	.26*	27.46
	.40 "	" "	" "	400	A	.6	.31*	.45
	.55 "	" "	" "	200	"	9.2	.34	.37
	1.05 "	" "	" "	100	"	.6	.35	.31
	.15 "	" "	" "	50	"	10.2	.31	.18
	.25 "	" "	" "	20	"	12.1	.33	26.85
	2.00 "	56° 35'	13° 58'	0	B	13.2	.27	.58
	4.00 "	56° 40'	14° 22'	0	"	12.7	.26	.67
	.00 "			19	A	.1	.265	.79
	.20 "			60	"	10.6	.31	27.11
	.32 "			102	"	8.7	.305	.42
	.45 "			145	"	.7	.295	.42
	6.00 "	56° 46'	14° 47'	0	B	12.8	.27	26.66
	.04 "			22	A	11.9	.32	.88
	.14 "			50	"	9.6	.30	27.27
	.24 "			100	"	8.9	.31	.40
	.44 "			170	"	.6	.26	.41
7	7.57 "	56° 50'	15° 07'	<u>250</u>				
	8.00 "	" "	" "	0	B	12.6	.26	26.69
	7.57 "	" "	" "	140	A	8.4	.21	27.40
	8.10 "	" "	" "	230	"	.25	.28	.48
	.20 "	" "	" "	54	"	9.2	.30	.34
	.27 "	" "	" "	28	"	11.3	.30	26.97
	10.00 "	56° 55'	15° 18'	0	B	12.6	.255	.69
	.15 "			18	A	.3	.29	.77
	.30 "			56	"	9.4		
	.50 "			102	"	.3	.34	27.35
	11.00 "			195	"	.1	.34	.39
	N	57° 03'	15° 37'	0	B	12.9	.26	26.63

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S‰	σ_t
8	July 1910	57° 10'	16° 00'	21	A	11.9	35.31	26.87
	8, 11.55 a. m.			50	"	.1?¹)	.30	27.01?
	N			100	"	9.7	.32	.27
	0.15 p. m.			190	"	.3	.34	.35
	.30 "			0	B	13.1	.30	26.62
	2.00 "			400	A	8.6	.295	27.44
	.05 "			200	"	9.0	.30*	.38
	.20 "			600	II	8.40	.28	.46
	.20 "			900	RB	7.95	.20	.47
	.43 "			100	A	9.4	.40*	.38
	.55 "			50	"	.6	.35	.31
	3.00 "			25	"	10.3	.34	.18
	4.00 "			0	B	13.7	.33	26.52
	.05 "			20	A	11.4		
	.13 "			50	"	9.4	.32	27.32
	.23 "			100	"	.3	.34	.35
	.35 "			150	"	.1	.30	.34
	6.00 "			0	B	12.5	.32	26.76
	.00 "			20	A	.1	.32	.84
	.08 "			50	"	10.8	.315	27.08
	.15 "			98	"	9.4	.34	.34
	.25 "			150	"	.2	.34	.37
	.48 "			390	"	8.7	.33*	.45
	7.05 "			270	"	9.05	.28*	.35
	.00 "			1000	RB	7.16	.18* ⁱ	.58
	.00 "			600	II	8.55	.28*	.44
	8.00 "			0	B	12.7	.28	26.69
	10.00 "			0	"	.4	.26	.73
9	.00 "	57° 23'	16° 59'	25	A	11.7	.26	.87
	.08 "			50	"	9.6	.26	27.24
	.21 "			100	"	.05	.26	.33
	.37 "			145	"	.1	.30*	.36
	M			0	B	12.0	.27	26.82
	M			17	A	11.4	.255	.92
	9, 0.09 a. m.			50	"	9.3	.26	27.29
	.22 "			100	"	.2	.26	.31
	.43 "			190	"	.2	.27	.32
	1.37 "			22	"	11.3	.26	26.94
	.47 "			55	"	10.8	.24	27.02
	2.10 "			95	"	9.2	.31*	.35
	.00 "			0	B	11.75	.28	26.87
	3.00 "			600	II	8.25	.25	27.46
	.00 "			1000	RB	6.70	.16* ⁱ	.62
	.32 "			400	II	8.37	.255	.44
	4.00 "			0	B	11.75	.27	26.87
	6.00 "			0	"	.8	.32	.90
	.00 "			20	A	.5	.31	.94
	.05 "			50	"	9.8	.28	27.22
	.15 "			95	"	.2²)	.28*	.32
10		57° 40'	18° 29'					

¹) The journal has 12.1° C., which is obviously an error, possibly for 11.1° C.

²) The journal has 8.2° C., but it should obviously be 9.2° C.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C	S‰	σ_t
11	July 1910							
	9, 6.30 a. m.			175	A	9.1 ¹⁾	35.29*	27.35
	8.00 "	57° 51'	19° 24'	0	B	11.9	.30	26.86
	.10 "			20	A	10.4 ¹⁾	.26	27.10
	.16 "			50	"	9.9		
	.30 "			100	"	.4	.27* ⁱ	.28
	.40 "			165	"	.3	.32	.34
	9.35 "	57° 55'	19° 46'	600	II	8.25	.235 ⁱ	.45
	" "	" "	" "	1000	RB	5.64	.09* ⁱ	.70
	.34 "	" "	" "	380	A	8.75	.26	.39
	.45 "	" "	" "	300	"	.9	.27	.37
	10.01 "	" "	" "	200	"	9.2	.31*	.35
	.00 "	57° 54'	19° 42'	0	B	11.9	.28	26.85
	.14 "			100	A	9.5	.31	27.30
	.23 "			48	"	10.1	.30*	.19
	.30 "			22	"	11.5	.31	26.94
	N	58° 02'	20° 24'	0	B	.2		
	11.55 "			30	A	10.8	.20	.99
	0.05 p. m.			52	"	9.7	.17	27.15
	.15 "			95	"	.3	.18*	.23
	.30 "			150	"	.15 ²⁾	.18 ⁱ	.25?
	2.00 "	58° 05'	20° 46'	0	B	11.1	.23	26.96
	1.55 "			25	A	10.8	.19	.98
	2.04 "			50	"	.15	.23	27.12
	.16 "			105	"	9.1	.23	.30
	.35 "			150	"	.1	.22*	.29
	4.00 "	58° 10'	21° 15'	0	B	10.8	.15	26.95
	.00 "			22	A	.6	.14	.97
	.10 "			45	"	9.9	.21	27.15
	.20 "			100	"	8.9	.20	.31
	.34 "			145	"	.6	.22	.37
	6.00 "	58° 17'	21° 43'	0	B	10.6	.165	26.99
	.00 "			17	A	.63	.17	.99
	.06 "			50	"	9.05	.20	27.29
	.17 "			105	"	8.5	.23	.40
	.30 "			140	"	.5	.24	.41
	7.35 "			185	"	.6	.26	.41
	.45 "			100	"	.9	.23	.33
	.50 "			55	"	10.1? ³⁾	.20	10? ²⁾
	.55 "			20	"	.9	.22	26.98
	8.00 "	58° 22'	22° 01'	0	B	11.1	.21	.94
12	" "	" "	" "	900 ⁴⁾	I	7.40	.15* ⁱ	27.51
	" "	" "	" "	1090 ⁴⁾	II	6.55	.08* ⁱ	.58
	" "	" "	" "	1380 ⁴⁾	RB	4.58	34.97* ⁱ	.73

¹⁾ The journal has 8.1° C. and 9.4° C., but it should obviously be 9.1° C. and 10.4° C.

²⁾ The journal has 8.15° C.; but it should probably be 9.15° C.

³⁾ The journal has 11.1° C., which may be an error for 10.1° C.

⁴⁾ 1500 metres of line were out, and the instruments were placed at 1000, 1200, and 1500 metres, but owing to the drift of the ship the line had at the sea-surface an angle of about 40° with the vertical. The depths have therefore been reduced to the probable values of 900, 1090, and 1380 metres.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water- bottle	t° C.	S ‰	σ _t
12	July 1910							
	{ 9, 9.00 p. m.	58° 22'	20° 01'	400	I	8.44	35.22	27.41
	.00 "	" "	" "	600	II	.13	.17	.42
	.00 "	" "	" "	800	RB	7.54	.15	.49
	10.00 "	58° 30'	21° 50'	0	B	11.9	.19	26.78
	M	58° 43'	21° 30'	0	"	.4	.21	.88
	10, 0.10 a. m.			20	A	.6	.31	.93
	.20 "			50	"	9.9	.255	27.18
	.30 "			95	"	.9	.26	.19
	.55 "			175	"	.1	.255	.32
	2.00 "	58° 59'	21° 10'	0	B	11.3	.21	26.90
	.05 "			18	A	.1	.165	.90
	.15 "			51	"	10.6	.25	27.06
	.30 "			100	"	9.1	.255	.32
	.45 "			[185]?	"	[10.5]	[.16]	[.01]
	4.00 "	59° 10'	20° 51'	0	B	11.2	.11	26.84
	.05 "			22	A	10.8	.14	.94
	.15 "			45	"	8.9	.17	27.29
	.30 "			100	"	.9	.19	.30
	.35 "			[165]?	"	[9.5]	[.15]	[.17]
	6.00 "	59° 22'	20° 30'	0	B	11.2	.01	26.77
	.00 "	" "	" "	19	A	10.85	.16	.95
	.10 "			50	"	9.05	.22 ⁱ	27.30
	.20 "			100	"	8.9	.20	.31
	.37 "			145	"	.9	.18	.30
	8.00 "	59° 34'	20° 12'	0	B	11.2	.12	26.85
	.00 "	" "	" "	20	A	10.2	.19	27.08
	.10 "			45	"	9.8	.17	.14
	.20 "			100	"	.1	.18 ⁱ	.26
	.37 "			200	"	8.8	.20	.33
	10.00 "	59° 50'	19° 54'	0	B	10.9	.17	26.95
	.00 "	" "	" "	21	A	.6	.17	27.00
	.08 "			45	"	9.8	.23	.18
	.17 "			102	"	.8	.21	.17
	.31 "			145	"	8.8	.23*	.35
	{ 11.10 "	59° 58'	19° 48'	1000	RB	5.77	.075 ⁱ	.67
	.10 "	" "	" "	600	II	8.12	.17	.42
	.10 "	" "	" "	400	I	.43	.165	.36
	N	60° 02'	19° 40'	0	B	11.4	.16	26.85
	2.00 p. m.	60° 16'	19° 20'	0	"	.2	.20	.91
	.00 "			20	A	10.9	.20	.97
	.09 "			48	"	9.9	.165	27.12
	.34 "			100	"	.4	.165	.20
	.50 "			145	"	8.9	.18	.30
	4.00 "	60° 28'	19° 01'	0	B	11.0	.17	26.93
	.00 "			20	A	10.7	.16	.97
	.10 "			48	"	9.9	.165	27.12
	.20 "			100	"	8.8	.17	.30
	.30 "			160	"	.7	.17	.32
	6.00 "	60° 42'	18° 42'	0	B	11.75	.18	26.80
	.05 "			18	A	10.75	.17	.97
	.10 "			45	"	9.9	.17	27.12
	.25 "			100	"	8.2	.18	.40
	.35 "			160	"	7.75	.19	.45

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S‰	σ_t
14	July 1910							
	10, 8.00 p.m.	60° 54'	18° 27'	400	I	7.81	35.17*	27.46
	" "	" "	" "	600	II	.57	.165	.50
	" "	" "	" "	1000	RB	5.80	.075* ¹	.67
	" "	" "	" "	0	B	11.6	.16	26.81
	.16 "	" "	" "	200	A	7.7	.21* ¹	27.51?
	.25 "	" "	" "	100	"	.9	.18* ¹	.45?
	.35 "	" "	" "	45	"	10.3	.18	.06
	.40 "	" "	" "	20	"	.35	.16	.04
	10.00 "	61° 01'	18° 10'	0	B	11.6	.08	26.75
	M	61° 14'	17° 59'	0	"	.5	.17	.84
	11, 0.04 a. m.			20	A	10.91	.16	.94
	.15 "			48	"	9.75	.17	27.15
	.27 "			100	"	.8	.165	.13
	.42 "			145	"	8.4	.21*	.40
	2.00 "	61° 26'	17° 39'	0	B	11.3	.19	26.89
	.10 "			20	A	10.9	.17	.95
	.20 "			50	"	8.95	.20*	27.30
	.33 "			100	"	.4	.25*	.41
	.46 "			145	"	7.9 ¹⁾	.18*	.45
	4.00 "	61° 39'	17° 19'	0	B	11.4	.19	26.87
	3.52 "			24	A	10.7	.17	.98
	4.00 "			50	"	9.35	.18	27.22
	.08 "			95	"	8.85	.185	.31
	.20 "			145	"	.1	.22*	.45
	6.00 "	61° 45'	16° 59'	0	B	11.2	.19	26.91
	.10 "			18	A	10.9	.165	.94
	.15 "			42	"	9.3	.17	27.22
	.20 "			95	"	.3	.20*	.25
	.35 "			145	"	8.3	.18	.39
	8.00 "	62° 04'	16° 39'	0	B	11.3	.20	26.90
	.00 "			18	A	.1	.17	.91
	.05 "			50	"	10.1	.19	27.10
	.15 "			95	"	9.5 ²⁾	.165	.18
	10.00 "	62° 13'	16° 15'	0	B	11.3	.17	26.87
	N	62° 20'	15° 56'	0	"	.3	.15	.86
15	11.45 "	" "	" "	20	A	.15	.155	.89
	.50 "	" "	" "	50	"	8.9	.165	27.28
	.55 "	" "	" "	100	"	.35	.19	.39
	N	" "	" "	200	"	7.9	.17	.44
	0.15 p. m.	" "	" "	300	"	.75	.17*	.47
	.40 "	" "	" "	400	I	.35	.14	.50
	.40 "	" "	" "	600	II	.04	.10	.52
	.40 "	" "	" "	1000	RB	5.09	.01*	.70
	2.00 "	62° 25'	15° 48'	0	B	11.4	.19	26.87
	4.00 "	62° 35'	15° 31'	0	"	.0		
	4.10 "			22	A	10.42	.17	27.03
	.18 "			57	"	9.65	.165	.16
	.27 "			100	"	8.15	.19	.42
	.37 "			220	"	7.7	.165	.47

¹⁾ The journal has 9.7° C., it may probably be an error for 7.9 C.

²⁾ The journal has 10.5° C., but this is evidently an error for 9.5° C.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water- bottle	t° C.	S‰	σ_t
16	July 1910							
	11, 6.00 p. m.	62° 46'	15° 13'	0	B	10.6	35.19	27.01
	.04 "			20	A	.43	.18	.035
	.11 "			55	"	8.5	.17	.35
	.24 "			100	"	.1	.165	.41
	.35 "			200	"	7.89	.18	.45
	7.25 "	62° 54'	15° 01'	22	"	8.95	.16	.27
	.30 "	" "	" "	53	"	.81	.18	.31
	.35 "	" "	" "	102	"	.3	.17	.38
	.50 "	" "	" "	200	"	7.6	.18	.50
	8.00 "	" "	" "	301	"	.4	.18	.53
	7.44 "	" "	" "	400	I	.40	.17	.52
	.44 "	" "	" "	600	II	.33	.16	.53
	.44 "	" "	" "	1000	RB	5.61	.075*	.69
	8.00 "	" "	" "	0	B	11.0	.18	26.94
	10.00 "	63° 04'	14° 44'	0	"	10.8		
	.00 "			23	A	.0	.18	27.11
	.05 "			55	"	8.8	.195	.32
	.15 "			105	"	.1	.18	.42
	.30 "			200	"	7.8	.18	.47
	M	63° 16'	14° 23'	0	B	10.7		
	M	" "	" "	22	A	9.4	.18	.21
17	12, 0.10 a. m.			52	"	.4	.16	.20
	.15 "			95	"	.2	.15	.22
	.30 "			165	"	8.6	.14	.31
	2.00 "	63° 28'	14° 03'	0	B	9.8	.21	.17
	.10 "			25	A	.1	.17	.25
	.15 "			48	"	.1	.16	.25
	.20 "			104	"	8.1	.165	.41
	.30 "			200	"	7.8	.21	.49
	4.00 "	63° 39'	13° 44'	0	B	9.4	.19	.22
	.05 "	" "	" "	600	A	7.2	.15	.54
	.30 "	" "	" "	400	"	.4	.16	.52
	.45 "	" "	" "	200	"	.6	.17	.49
	.50 "	" "	" "	102	"	8.2	.16	.39
	.55 "			55	"	.6	.17	.34
	5.00 "			25	"	9.2	.165	.23
	6.00 "	63° 45'	13° 34'	0	B	.6	.15	.16
	.05 "			24	A	.0	.165	.27
	.15 "			55	"	8.33	.165	.37
	.26 "			100	"	7.81	.17	.46
	.39 "			200	"	.45	.17	.51
	8.00 "	63° 57'	13° 14'	0	B	9.9	.24	.17
	.00 "	" "	" "	20	A	.3	.15	.20
	.09 "	" "	" "	50	"	8.9	.045*	.19
18	.35 "	63° 59'	13° 09'	600		coarse sand		
	.54 "	" "	" "	500	A	3.2	34.99	27.88
	9.05 "	" "	" "	400	"	5.5	35.05	.68
	.25 "	" "	" "	300	"	6.95	.15	.57
	.35 "	" "	" "	200	"	7.35	.165	.52
	.50 "			100	"	7.65	.165 ⁱ	.48
	10.00 "	64° 05'	13° 00'	0	B	9.6	.16	.16
	N	64° 17'	12° 29'	0	"	9.1	.03	.15

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S‰	σ_t
19	July 1910							
	12, 11.35 a.m.	64° 17'	12° 29'	480				
	.39 "	" "	" "	450	A	— 0.15	34.805* ⁱ	27.98
	0.10 p.m.	" "	" "	305	"	.4	.75 ⁱ	.95
	.20 "	" "	" "	220	"	2.05	.74	.785
	.30 "	" "	" "	400	"	0.1	.77	.93
	.45 "	" "	" "	105	"	7.1	35.10	.50
	.50 "			50	"	.6	.01	.36
	.57 "			22	"	.56	34.695	.12
	2.00 "	64° 29'	12° 29'	0	B	9.6	.56	26.70
	.00 "	" "	" "	155	A	0.1	.77	27.93
	.15 "	" "	" "	100	"	.01	.75	.92
	.26 "			55	"	1.33	.72	.82
	.32 "			25	"	3.4	.605	.555
20	4.00 "	64° 41'	12° 29'	0	B	9.3	.49	26.69
	.06 "	" "	" "	155	A	0.01	.76	27.93
	.14 "	" "	" "	100	"	.31	.695	.86
	.24 "			50	"	1.6	.68	.77
	.30 "			25	"	3.4		
	6.00 "	64° 54'	12° 20'	0	B	9.4	.59	26.75
	.10 "			175	A	0.1	.73	27.90
	.30 "			97	"	.2	.72	.89
	.40 "			55	"	.55	.71	.86
	.45 "			25	"	3.6	.58	.51
21	8.00 "	64° 57'	12° 06'	0	B	10.0	.38	26.50
	.00 "	" "	" "	104	A	0.3	.72	27.88
	.05 "			52	"	1.7	.66	.75
	.15 "			10	"	4.6	.28	.17
	9.55 "			50	"	2.9	.42	.45
	10.00 "	65° 10'	12° 52'	25	"	3.45	.34	.34
	.00 "	" "	" "	0	B	4.00	.36	.30
	M	Mouth of Seydis Fjord		0	"	5.4	33.15	26.19
	16, 4.50 "	65° 12'	13° 37'	0	"	10.7	28.91	22.12
	.50 "	Mouth of Mjø Fjord		50	A	2.4	34.51	27.57
	.55 "			20	"	4.2	.79	.62
	5.25 "			45	"	2.2	.43	.52
	.33 "	65° 12'	13° 20'	25	"	4.0	.16	.14
	6.30 "			50	"	2.2	.53	.60
22	.36 "			30	"	4.0	.31	.26
	7.00 "	65° 11'	13° 8'	0	B	5.0		
	.30 "	65° 10'	12° 52'	180				
	.35 "	" "	" "	160	A	0.5	.695	.85
	.45 "	" "	" "	100	"	0.4	.695	.86
	.50 "	" "	" "	50	"	1.7	.61	.70
	.55 "			22	"	4.1	.47	.37
	9.00 "	65° 08'	12° 32'	0	B	6.5	33.78	26.55
	.20 "			260	A	— 0.3		
	.30 "			240	"	— 0.1	34.75*	27.93
23	.35 "			95	"	0.5	.71	.87
	10.20 "	65° 07'	12° 16'	210				
	.30 "	" "	" "	165	"	— 0.1	.765*	.94
	.35 "	" "	" "	95	"	0.2	.75	.91
	.37 "	" "	" "	52	"	0.4	.70	.86
	.42 "			20	"	5.4	.51	.26

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C	S‰	σ_t
24	July 1910 16, 11.00 p. m.	65° 06'	12° 14'	0	B	6.4	34.42	27.06
	.45 "	65° 05'	11° 59'	250				
	.50 "	" "	" "	204	A	— 0.3	.77	.96
	.55 "	" "	" "	103	"	1.3	.75	.85
	M	" "	" "	52	"	2.0	.68	.74
25	17, 0.05 a. m.			23	"	4.3	.53	.40
	1.00 "	65° 04'	11° 46'	0	B	5.8	.54	.24
	.45 "	65° 03'	11° 40'	450				
	2.05 "	" "	" "	380	A	— 0.4	.85	28.03
	.20 "	" "	" "	202	"	— .4	.78	27.97
26	.27 "	" "	" "	100	"	.5	.77	.91
	.32 "	" "	" "	52	"	3.0	.67	.65
	.37 "	" "	" "	23	"	5.3	.515	.27
	3.00 "	65° 02'	11° 25'	0	B	6.6	.57	.16
	4.35 "	65° 00'	11° 00'	500				
27	.45 "	" "	" "	450	A	— 0.25	.89	28.05
	5.05 "	" "	" "	200	"	.7	.79	27.92
	.15 "	" "	" "	100	"	4.6	.96	.71
	.00 "	" "	" "	0	B	8.6	35.03	.23
	.25 "	" "	" "	50	A	7.0	.08	.50
28	.30 "	" "	" "	30	"	.4	.075	.44
	7.00 "	64° 52'	10° 32'	0	B	.2	34.84	.29
	.25 "	64° 50'	10° 24'	580				
	.30 "	" "	" "	500	A	— 0.3	.89*	28.05
	.45 "	" "	" "	300	"	.1	.86*	.02
29	.55 "	" "	" "	200	"	.4	.85	27.98
	8.10 "	" "	" "	100	"	2.5	.875	.85
	.15 "	" "	" "	50	"	4.62	.89	.65
	.23 "	" "	" "	25	"	6.75	.87	.37
	9.00 "	64° 47'	10° 12'	0	B	7.9	.87	.21
28	10.05 "	" "	" "	25	A	8.35	35.14	.35
	.15 "	" "	" "	50	"	6.6	.065	.55
	.30 "	64° 40'	9° 46'	500	"	— 0.4	34.925*	28.08
	.36 "	" "	" "	500	I	— .25	.93	.08
	.36 "	" "	" "	600	II	— .46	.93*	.09
29	.36 "	" "	" "	980	RB	— .80	.92*i	.10
	.45 "	" "	" "	400	A	.0	.87	.02
	.57 "	" "	" "	202	"	.1	.79	27.95
	11.06 "	" "	" "	102	A	3.7	.89	.75
	.00 "	" "	" "	0	B	9.5	35.07	.11
29	1.00 p. m.	64° 25'	9° 22'	0	B	8.2	34.92	.20
	.05 "	" "	" "	250	A	0.75	.875	.98
	.25 "	" "	" "	100	"	1.75	.77	.83
	.35 "	" "	" "	60	"	4.1	.93	.74
	.45 "	" "	" "	30	"	6.2	.95	.51
29	3.00 "	64° 25'	8° 53'	0	B	.9	.88	.36
	.40 "	" "	" "	240	A	[2.2]? ¹⁾	.875	[.88]
	4.30 "	64° 20'	8° 34'	200	II	0.60	.845*	.97
	.30 "	" "	" "	400	RB	— .11	.87	28.03
	.30 "	" "	" "	600	I	— .41	.915*	.08

¹⁾ The temperature is much too high, as the water-bottle was hauled up too slowly.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S‰	σ _t
29	July 1910							
	17, 4.30 p.m.	64° 20'	8° 34'	200	A	0.5	34.84*	27.97
	.45 "	" "	" "	100	"	2.3	.85	.85
	.50 "	" "	" "	52	"	4.7	.815*	.58
	.55 "	" "	" "	23	"	6.4	.92	.46
	5.00 "	64° 19'	8° 32'	0	B	7.9	.93	.25
	6.30 "			170	A	0.5	.87	.99
	.45 "			105	"	2.15	.85	.86
	.55 "			45	"	3.2	.87	.79
	7.05 "			25	"	4.95	.85	.58
	.00 "	64° 12'	8° 05'	0	B	7.8	.90	.25
	8.25 "	64° 06'	7° 48'	200	I	0.57	.86	.98
30	.25 "	" "	" "	400	II	.14	.88	28.02
	.25 "	" "	" "	600	RB	— .33	.90	.06
	.10 "	" "	" "	200	A	.65	.84	27.96
	.20 "	" "	" "	100	"	1.95	.83*	.86
	.30 "	" "	" "	50	"	4.7	.93	.68
	.35 "	" "	" "	22	"	6.45	.995*	.51
	9.00 "	64° 04'	7° 40'	0	B	8.3	35.02	.26
	11.00 "	63° 57'	7° 15'	0	"	.6	34.97*	.18
	.35 "			24	A	6.2	.90	.47
	.45 "			50	"	4.0	.79	.64
	.53 "			100	"	2.7	.875	.84
	18, 0.03 a.m.	63° 50'	7° 01'	200	"	0.6	.87	.99
31	.14 "			400	"	— .23	.93	28.08
	1.00 "	63° 47'	6° 53'	0	B	8.8	35.03	27.19
	3.00 "	63° 40'	6° 28'	0	"	9.2	.16	.23
	.35 "			50	A	7.63	.17	.48
	.44 "			20	"	8.9	34.83	.02
	.50 "			100	"	3.2	.95	.85
	4.05 "	63° 35'	6° 15'	200	"	1.93	.92*	.93
	.17 "			400	"	0.5	.94*	28.05
	5.00 "	63° 33'	6° 07'	0	B	9.8	.84	26.88
	7.00 "	63° 24'	5° 40'	0	"	.4	.81	.92
	8.05 "			400	A	0.1	.87*	28.02
	.15 "	63° 19'	5° 26'	200	"	.95	.86	27.96
32	.25 "			300	"	.4	.88*	28.01
	.30 "			102	"	2.1	.51?	27.59?
	.35 "			52	"	4.65	.84	.61
	.40 "			22	"	8.65	.85	.08
	9.00 "	63° 18'	5° 23'	0	B	9.4	.85	26.96
	11.00 "	63° 11'	5° 02'	0	"	10.0	35.15	27.09
	1.00 p.m.	63° 04'	4° 38'	0	"	.4	.10	26.98
	.05 "	" "	" "	400	A	0.03	34.90	28.04
	.20 "	" "	" "	200	"	1.55	.87	27.93
	.27 "	" "	" "	300	"	0.49	.87	.99
	.33 "	" "	" "	100	"	4.20	.95	.75
	.45 "			51	"	6.94	35.07	.50
34	.55 "			25	"	7.90	.00	.31
	3.00 "	63° 02'	4° 18'	0	B	10.4	.20	.06
	5.00 "	" "	" "	0	"	.3	[35.28 ¹⁾]	[.14]

1) The rubber washer was defective.

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S ‰	σ_t
35	July 1910							
	18, 6.50 p. m.	62° 56'	3° 44'	1240				
	7.00 "	" "	" "	0	B	10.3	35.13	27.02
	.17 "	" "	" "	400	A	0.49	34.89*	28.01
	.36 "	" "	" "	200	"	2.74	.90	27.85
	.40 "	" "	" "	300	"	0.64	.85*	.97
	.50 "	" "	" "	100	"	6.45	35.14	.627
	.57 "	" "	" "	52	"	7.42	.14	.49
	8.05 "	" "	" "	30	"	8.32	.18	.385
	9.00 "	62° 51'	4° 03'	0	B	10.4	.165	.03
36	.55 "	62° 48'	4° 10'	1300				
	.35 "	" "	" "	210	A	3.7	34.94	.79
	.45 "	" "	" "	102	"	6.9	35.17	.59
	.55 "	" "	" "	53	"	7.52	.155	.49
	10.00 "	" "	" "	300	"	0.9	34.81	.92
	.05 "	" "	" "	26	"	9.05	35.165	.26
	.20 "	" "	" "	400	I	1.06	34.89	.97
	.20 "	" "	" "	500	II	0.34	.895*i	28.02
	11.00 "	62° 46'	4° 18'	0	B	10.4	35.14	27.01
	19, 0.30 a. m.	62° 40'	4° 35'	780				
37	.20 "	" "	" "	300	A	0.55	34.87	.99
	.30 "	" "	" "	200	"	1.3	.83	.91
	.40 "	" "	" "	100	"	4.55	.96	.72
	.52 "	" "	" "	50	"	7.4	35.02	.40
	.57 "	" "	" "	22	"	8.4	.07	.29
	.50 "	" "	" "	400	I	0.05	34.86	28.01
	.50 "	" "	" "	600	II	— .40	.91	.07
	1.00 "	" "	" "	0	B	10.9	35.12	26.91
	2.50 "	62° 33'	5° 01'	500				
	.50 "	" "	" "	301	A	5.65	35.01	27.63
38	3.00 "	" "	" "	200	"	7.35	.165	.52
	.00 "	" "	" "	0	B	9.95	.16	.10
	.10 "	" "	" "	400	I	2.22	34.84	.85
	.10 "	" "	" "	104	A	7.65	35.17	.48
	.15 "	" "	" "	50	"	8.05	.20	.45
	.20 "	" "	" "	25	"	.75	.19	.33
	5.00 "	62° 27'	5° 23'	0	"	10.00	.20	.13
	.15 "	62° 25'	5° 27'	207				
	.20 "	" "	" "	197	A	7.4		
	.30 "	" "	" "	100	"	.6		
39	.35 "	" "	" "	50	"	8.2		
	.40 "	" "	" "	20	"	9.5		
	7.00 "	62° 16'	5° 07'	0	B	.8	.20	.16
	8.35 "	62° 08'	4° 40'	286				
	.40 "	" "	" "	250	A	7.3	.17	.53
	.52 "	" "	" "	200	"	.45	.20	.54
	.57 "	" "	" "	100	"	.8	.24	.51
	9.00 "	" "	" "	55	"	8.15	.225	.45
	.05 "	" "	" "	22	"	9.6	.23	.22
	10.00 "	62° 03'	4° 28'	0	B	10.1	.17	.09
40	11.10 "	61° 58'	4° 16'	450				
	.26 "	" "	" "	300	I	2.70	34.90*i	.86
	.26 "	" "	" "	430	II	— 0.31	.92*i	28.08

Stat. No.	Date and Hour l. t.	N. Lat.	W. Long.	Depth Metres	Water-bottle	t° C.	S‰ ₀₀	σ_t
41	July 1910							
	{ 19, 11.25 a.m.	61° 58'	4° 16'	200	A	5.75	35.05	27.65
	.33 "	" "	" "	100	"	7.42	.16	.51
	.40 "	" "	" "	55	"	.83	.15 ^{*i}	.44
	.45 "	" "	" "	25	"	8.79	34.965	.14
	N	61° 57'	4° 11'	0	B	9.6	.68	26.79
	1.00 p.m.	61° 55'	4° 06'	0	"	11.2	35.20	.91
	{ 2.00 "	61° 50'	3° 45'	850				
	.05 "	" "	" "	300	A	5.6	.05	27.67
	.10 "	" "	" "	200	"	7.1	.13	.53
42	.15 "	" "	" "	103	"	.7	.16 ^{*i}	.47
	.18 "	" "	" "	50	"	9.05	.165 ^{*i}	.26
	.21 "	" "	" "	22	"	10.15	.16	.07
	.30 "	" "	" "	410	II	3.51	34.94	.81
	.30 "	" "	" "	615	I	0.31	.885 [*]	28.015
	.30 "	" "	" "	820	RB	— .62	.88 [*]	.06
	3.00 "	61° 49'	3° 43'	0	B	11.3	35.23	26.92
	5.00 "	61° 44'	3° 20'	0	"	.6	.24	.87
	.30 "	61° 43'	3° 18'	400	II (I?)	4.15	34.95	27.76
	.30 "	" "	" "	600	I (II?)	0.25	.89 [*]	28.02
43	.30 "	" "	" "	800	RB	— .38	.89 [*]	.06
	.15 "	" "	" "	300	A	7.15	35.12	27.52
	.30 "	" "	" "	200	"	7.45	.16	.50
	.40 "	" "	" "	103	"	8.35	.22	.41
	.45 "	" "	" "	52	"	8.85	.22	.33
	.55 "	" "	" "	23	"	10.9	.26	.02
	7.00 "	61° 41'	3° 13'	0	B	11.6	.255	26.88
	8.20 "	61° 35'	2° 49'	400	I	0.46	34.86	27.99
	.20 "	" "	" "	600	II	— .33	.89	28.05
	.20 "	" "	" "	800	RR	— .63	.90 [*]	.08
44	.05 "	" "	" "	300	A	1.92	.86	27.89
	.15 "	" "	" "	200	"	5.92	35.12	.63
	.25 "	" "	" "	100	"	7.4	.165	.51
	.30 "	" "	" "	50	"	8.3	.20	.40
	.35 "	" "	" "	20	"	9.25	.15	.21
	9.00 "	61° 33'	2° 43'	0	B	11.4	.20	26.88
	11.00 "	61° 28'	2° 21'	0	"	.3	[.68] ¹⁾	
	10.58 "	" "	" "	400	I	0.45	.885 ^{*i}	28.01
	.58 "	" "	" "	500	II	— .15	[.04] ²⁾	
	.58 "	" "	" "	600	RB	— .41	34.92	.09
45	11.55 "	" "	" "	100	I	7.69	35.19	27.49
	.55 "	" "	" "	200	II	6.76	.08 ^{*i}	.54
	.55 "	" "	" "	300	RB	1.83	34.89 ⁱ	.92
	20, 0.05 a. m.	" "	" "	22	A	8.64	35.145	.31
	.10 "	" "	" "	50	"	.07 ³⁾	.14	.39
	1.00 "	61° 25'	2° 10'	0	B	10.8	.09	26.90
	2.25 "	61° 20'	1° 55'	680				
	.25 "	" "	" "	400	I	4.74	.00	27.73

¹⁾ The rubber washer was defective.

²⁾ The glass bottle was cracked; later titrations gave 35.07, 35.25, and even 36.29‰.

³⁾ The journal has 3.07° C., which is evidently an error for 8.07° C.

Stat. No.	Date and Hour l. t.	N. Lat.	Long.	Depth Metres	Water- bottle	t° C.	S ^o / ₁₀₀	σ_t
	July 1910		W					
46	20, 2.25 a. m.	61° 20'	1° 55'	500	II	1.73	34.89*	27.93
	.25 "	" "	" "	650	RB	— 0.91	.885*	28.08
	.15 "	" "	" "	110	A	7.9	35.17	27.44
	.25 "	" "	" "	50	"	8.75	.16	.30
	.35 "	" "	" "	20	"	10.7	.16	26.97
	.37 "	" "	" "	300	"	6.7	.13	27.59
	.50 "	" "	" "	200	"	7.6	.18	.50
47	3.00 "	61° 19'	1° 53'	0	B	10.9	.075	26.87
	5.00 "	61° 14'	1° 36'	0	"	11.6	.255	.88
	.30 "	61° 13'	1° 28'	265				
	.30 "	" "	" "	204	A	8.5	.32 ⁱ	27.47
	.37 "	" "	" "	100	"	.8	.25* ⁱ	.37
	.41 "	" "	" "	48	"	9.55	.31* ⁱ	.29
	.47 "	" "	" "	22	"	11.7	.30* ⁱ	26.90
48	7.00 "	61° 11'	1° 10'	0	B	.7	.27	.88
	8.00 "	10'	0° 54'	25	A	.82	.30	.88
	.05 "	" "	" "	50	"	9.22	.29	27.33
	.15 "	" "	" "	100	"	8.81	.30	.40
	.25 "	" "	" "	150	"	.1	.27	.49
	9.00 "	61° 09'	0° 44'	0	B	12.5	.27	26.72
	11.00 "	08'	28'	0	"	.4	.29	.75
	1.00 p. m.	07'	10'	0	"	.5	.31	.75
			E					
	3.00 "	05'	18'	0	"	13.2	.23	.55
	5.00 "	02'	48'	0	"	.1	33.19*	24.99
	7.00 "	00'	1° 18'	0	"	.05	.17	.98
	9.00 "	60° 58'	48'	0	"	.0	.21	25.02
	11.00 "	56'	2° 15'	0	"	12.6	.21	.10
	21, 1.00 a. m.	54'	45'	0	"	11.9	.395	.38
	3.00 "	52'	3° 12'	0	"	.0	.58	.70
	5.00 "	49'	45'	0	"	7.8	34.12	26.63
	7.00 "	47'	4° 14'	0	"	8.0	33.86	.39

Literature.

- 1910—1911. **Bjerknes, V.**, Dynamic Meteorology and Hydrography. Carnegie Institution of Washington. Part I, 1910; Part II, 1911.
1909. **Brennecke, W.**, Ozeanographie. Forschungsreise S. M. S. „Planet“ 1906—1907. Herausgeg. v. Reichs-Marine-Amt. Bd. III, Berlin 1909.
1911. **Brennecke, W.**, Ozeanographische Arbeiten der Deutschen Antarktischen Expedition, I. Ann. d. Hydrographie u. Marit. Meteorologie. Hamburg 1911.
1851. **Buff, Henry**, Familiar Letters on the Physics of the Earth; treating of the chief Movements of the Land, the Water, and the Air, and the Forces that give rise to them. London 1851.
1895. **Buchan, Alexander**, Report on Oceanic Circulation, based on the Observations made on board H. M. S. Challenger, and other Observations. Chall. Rep. Summary of Results, Part II, 1895.

1885. **Buchanan, John Y.**, In *Challenger Reports. Narrative*, vol. I, 2nd Part, Chapt. XXII, 1885.
1888. **Buchanan, John Y.**, *Scottish Geograph. Magazine*, Edinburgh 1888.
1871. **Carpenter, William B.**, On the Gibraltar Current, the Gulf Stream, and the General Oceanic Circulation. *Proc. Royal Geogr. Soc.*, vol. XV, London, 1871.
1872. **Carpenter, William B.**, Report on Scientific Researches carried on during the Months of August, September, and October 1871, in H. M. Surveying-ship *Shearwater*. *Proc. R. Soc. London*, vol. XX, 1872.
1874. **Carpenter, William B.**, Further Inquiries on Oceanic Circulation. *Proc. Royal Geographical Society*, vol. XVIII, London 1874.
1875. **Carpenter, William B.**, Summary of Recent Observations on Ocean Temperature made in H. M. S. 'Challenger', and U. S. S. 'Tuscarora': with their bearing on the Doctrine of a General Oceanic Circulation sustained by Difference of Temperature. *Proc. R. Soc. London*, vol. XIX, 1875.
1870. **Carpenter, William B.**, **Jeffreys, Gwyn J.** and **Thomson, Wyville**, Preliminary Report of the Scientific Exploration of the Deep Sea in H. M. Surveying-vessel 'Porcupine', during the Summer 1869. *Proc. Royal Soc. London*, vol. XVIII, 1870.
1871. **Carpenter, William B.** and **Jeffreys Gwyn J.**, Report on Deep-sea Researches carried on during the Months of July, August and September 1870, in H. M. Surveying-ship 'Porcupine'. *Proc. Royal Society, London*, vol. XIX, 1871.
1905. **Castens Gerh.**, Untersuchungen über die Strömungen des Atlantischen Ozeans. Dichte und Windverhältnisse (Kieler Dissetr.). Kiel 1905.
1870. **Colding, A.**, Om Strømningsforholdene i almindelige Ledninger og i Havet. *Vidensk. Selskabs Skrifter, 5te Raekke naturvid. og math. Afd.*, Bd. IX, No. 3. København 1870.
- 1870—1874. **Croll, James**, On Ocean-currents. *Phil. Mag.*, S. 4, vols. XXXIX, XL, 1870; XLII, 1871; XLVII, 1874.
1900. **Dickson, H. N.**, The Circulation of the Surface Waters of the North Atlantic Ocean. *Philos. Trans. R. Soc. London*, Ser. A, vol. 196, 1901.
1902. **Deutsche Seewarte**, Atlantischer Ozean. Atlas, 2. Aufl., Hamburg 1902.
1902. **Ekman, V. Walfrid**, Om Jordrotationens Inverkan på Vindströmmar i Hafvet. *Nyt Magazin f. Naturvidenskab*, Bd. XL, Kristiania 1902.
1905. **Ekman, V. W.**, On the Influence of the Earth's Rotation on Ocean-Currents. *Arkiv för Matematik, Astronomi och Fysik*, Bd. II, Stockholm 1905.
1906. **Ekman, V. W.**, Beiträge zur Theorie der Meeresströmungen. *Ann. d. Hydr. u. Marit. Meteorol.*, Bd. XXXIV, Hamburg 1906 (Reprint).
1882. **Ferrel, W.**, The Motions of Fluids and Solids on the Earth's Surface, reprinted by Frank Waldo, Washington 1882.
1869. **Findlay, A. G.**, On the Gulf Stream. *Proc. Royal Geogr. Soc. London*, vol. XIII, 1869.
1907. **Gehrke, Johan**, Mean Velocity of the Atlantic Currents running North of Scotland and through the English Channel. *Publications de Circoustance*, No. 40, Copenhagen 1907.
1910. **Gehrke, J.**, Beiträge zur Hydrographie des Ostseebassins. *Publications de Circoustance*, No. 52, Copenhagen 1910.
1912. **Gehrke, J.**, Om vertikale Varmestrømme i Havet. København 1912.
1872. **Guldberg, Cato M.**, Theorien for vaudets og luftens strømninger på jordens overflade. *Polyteknisk Tidsskrift*, XIX, Christiania 1872.
1905. **Helland-Hansen, Björn**, Report on Hydrographical Investigations in the Faeroe-Shetland Channel and the northern Part of the North Sea in 1902. Report on Fishery and Hydrographical Investigations in the North Sea and Adjacent Waters. Publ. by Fishery Board for Scotland. Edinburgh 1905.
1907. **Helland-Hansen, Björn**, De vestlandske Østersbasinens Naturforhold. Published by Selskabet for de Norske Fiskeriers Fremme, Bergen 1907.

1908. **Helland-Hansen, B.**, Die Austernbassins in Norwegen. Internationale Revue der gesamten Hydrobiologie und Hydrographie. Bd. I, Leipzig 1908.
1911. **Helland-Hansen, B.**, Neue Forschungen im nördlichen Atlantischen Ozean. Zeitschr. d. Gesellsch. f. Erdkunde, Berlin 1911.
1912. **Helland-Hansen, B.**, Physical Oceanography. In John Murray and Johan Hjort, The Depths of the Ocean. London 1912, Chap. V.
1909. **Helland-Hansen, B.**, and **Koefoed, E.**, Hydrographie. In Duc d'Orléans, Croisière océanographique 1905, Bruxelles 1909.
1909. **Helland-Hansen, B.**, and **Nansen, F.**, The Norwegian Sea. Report on Norwegian Fish. and Marine Investigations. Vol. II, No. 2. Kristiania 1909.
1861. **Herschel, John F. W.**, Physical Geography. In Encycl. Britannica, Edinburgh 1861.
1910. **Hjort, Johan**, The "Michael Sars" North Atlantic Deep Sea Expedition 1911 etc. List of Observing Stations etc., Bergen 1910.
1911. **Hjort, J.**, "Michael Sars" Atlanteshavsekspedition 1910. Naturen, Bergen 1911.
1911. **Hjort, J.**, The "Michael Sars" North Atlantic Deep-Sea Expedition 1910. Geogr. Journal. Vol. XXXVII, London 1911.
1911. **Hjort, J.**, See also Intern. Revue d. g. Hydr. Bd. IV, S. 152, 335. Leipzig 1911.
1908. **Jacobsen, J. P.**, Der Sauerstoffgehalt des Meereswassers in den dänischen Gewässern innerhalb Skagens. Meddelelser fra Kommissionen for Havundersøgelser. Ser. Hydrografi, Bd. I. No. 12, København 1908.
1899. **Knudsen, Martin**, Hydrography. The Danish Ingolf-Expedition. Vol. I. No. 2, Copenhagen 1899.
1905. **Knudsen, Martin**, Contributions to the Hydrography of the North Atlantic Ocean. Meddelelser fra Kommissionen for Havundersøgelser. Ser. Hydrografi, Bd. I, No. 6, København 1905.
1811. **Knudsen, Martin**, Danish Hydrographical Investigations at the Faroe Islands in the Spring of 1910. Medd. f. Komm. f. Havundersøgelser. Ser. Hydrografi, Bd. II, No. 1, København 1911.
1893. **Krümmel, Otto**, Geophysikalische Beobachtungen der Plankton-Expedition. Ergebnisse der Plankton-Expedition der Humboldt-Stiftung. Bd. I, C. Kiel und Leipzig 1893.
1907. **Krümmel, Otto**, Handbuch der Ozeanographie. Bd. I, Stuttgart 1907.
1911. **Krümmel, Otto**, Handbuch der Ozeanographie. Bd. II, Stuttgart 1911.
1847. **Lenz, E.**, Bemerkungen über die Temperatur des Weltmeeres in verschiedenen Tiefen. Bull. phys.-math. de l'Acad. de St. Petersburg, T. V, 1847. See also Poggendorfs Annalen, Ergänzungsbd. II, 1848.
1912. **Marchi, Luigi de**, La distribuzione verticale della salsedine e della temperatura e i movimenti convettivi verticali in mare. R. Comitato Talassografico Italiano. Memoria VI. 1912.
1905. **Matthews, Donald J.**, Report on the Physical Conditions in the English Channel, 1903. First Report on Fishery and Hydrogr. Invest. in the North Sea and Adjacent Waters (Southern Area) 1902—1903. Marine Biological Association of the United Kingdom. London 1905.
1907. **Matthews, Donald J.**, The Surface Waters of the North Atlantic Ocean south of 60° N. Latitude, September 1904 to December 1905. Second Report (Southern Area) on Fishery and Hydrographical Investigations in the North Sea and Adjacent Waters. 1904—1905, Part I. North Sea Fisheries Investigation Committee. London 1907.
1909. **Matthews, Donald J.**, Report on the Physical Conditions in the English Channel and adjacent Waters, 1904 and 1905. Second Report (Southern Area) on Fish. and Hydrogr. Invest. etc., 1904—1905, Part II. North Sea Fisheries Investigation Committee. London 1909.
1911. **Matthews, Donald J.**, Report on the Physical Conditions in the English Channel and adjacent Waters, 1905 with a note on the mean conditions for 1903—1909. Third Report (Southern Area) on Fish. a. Hydr. Invest. etc. North Sea Fish. Inv. Comm., London 1911.
1860. **Maury, M. F.**, The Physical Geography of the Sea and its Meteorology. 8th ed. London 1860.

1887. **Mohn, H.**, The North Ocean, its Depths, Temperature, and Circulation. The Norwegian North-Atlantic Expedition 1876—78. Christiania 1887.
1869. **Mühry, A.**, Lehre von den Meeresströmungen. Göttingen 1869. See also Peterm. Mitt. 1874.
1884. **Murray, John**, Report on the Deep-sea Temperature Observations obtained by the Officers of H. M. S. Challenger during the years 1873—76. Challenger Rep. Physics and Chemistry, vol. I. 1884.
1912. **Murray, John**, and **Hjort, Johan**, The Depths of the Ocean. London 1912.
1901. **Nansen, F.**, Some Oceanographical Results of the Expedition with the Michael Sars 1900. Nyt Magazin f. Naturvidenskab, Bd. XXXIX. Kristiania 1901.
1902. **Nansen, F.**, The Oceanography of the North Polar Basin. The Norwegian North Polar Expedition 1893—96. Scientific Results. Vol. III, No. 9, Christiania 1902.
1904. **Nansen, F.**, The Bathymetrical Features of the North Polar Seas. Norw. N. Pol. Exped. 1893—96. Scient. Res. Vol. IV, No. 13. Christiania 1904.
1905. **Nansen, F.**, Die Ursachen der Meeresströmungen. Petermanns geogr. Mitteilungen 1905. Heft I und II. Gotha.
1906. **Nansen, F.**, Northern Waters. Captain Roald Amundsen's oceanographic observations in the Arctic Seas in 1901 etc. Vid. Selskabets Skriffter 1906. I. Math.-naturw. Kl. No. 3. Christiania 1906.
1912. **Nansen, F.**, Das Bodenwasser und die Abkühlung des Meeres. Internationale Revue d. gesamten Hydrobiologie u. Hydrographie. Bd. V, Heft 1. Leipzig 1912.
1904. **Nielsen, J. N.**, Hydrography of the Waters by the Faroe Islands and Iceland during the Cruises of the Danish Research Steamer Thor in the Summer 1903. Meddelelser fra Kommissionen f. Havundersøgelser. Serie Hydrografi, Bd. I, No. 4. København 1904.
1905. **Nielsen, J. N.**, Contributions to the Hydrography of the Waters North of Iceland. Medd. f. Komm. f. Havundersøg. Serie Hydrografi, Bd. I, No. 7. København 1905.
1907. **Nielsen, J. N.**, Contribution to the Hydrography of the North-eastern Part of the Atlantic Ocean. Medd. f. Komm. f. Havundersøg. Serie Hydrografi. Bd. I, No. 9. København 1907.
1870. **Petermann, A.**, Der Golfstrom und Standpunkt der thermometrischen Kenntnis des Nord-Atlantischen Ozeans und Landgebiets im Jahre 1870. Petermanns Mitteilungen, Bd. XVI, Gotha 1870.
1900. **Pettersson, Otto**, Die hydrographischen Untersuchungen des Nordatlantischen Ozeans in den Jahren 1895—1896. Petermanns Mitteilungen 1900.
1847. **Pouillet, Eléments de Physique**. 5ième éd., tom. II, 1847.
1793. **Rennell, James**, Observations on a Current that often prevails to the Westward of Scilly, endangering the Safety of Ships that approach the British Channel. Philos. Transactions, R. Soc. London. Vol. LXXXIII, Part II, 1793.
1815. **Rennell, James**, Some farther observations, on the current that often prevails, to the westward of the Scilly Islands. Philos. Transactions, R. Soc. London. Vol. CV, Part. II, 1815.
1907. **Robertson, A. J.**, Report on Hydrographical Investigations in the Faeroe-Shetland Channel and the Northern Part of the North Sea during the years 1904—1905. Second Report on Fishery and Hydrographical Investigations in the North Sea and Adjacent Waters 1904—1905. Part 1. North Sea Fisheries Investigations Committee.
1888. **Rottok**, Die während der Forschungsreise S. M. S. „Gazelle“ ausgeführten Tiefseelothungen, Wassertemperaturmessungen, Strombestimmungen und Beobachtungen über die Farbe und Durchsichtigkeit des Meerwassers. Die Forschungsreise S. M. S. „Gazelle“ 1874—76. Herausgeg. v. d. Hydrographischen Amt der Admiralität. Bd. II. Berlin 1888.

1868. **Sary**, *Annales Hydrogr.* 1868. *Compt. Rend. de l'Acad.* LXVII, p. 483; LXVIII, p. 522.
1910. **Schmidt, Johs., Nielsen, J. N. and Jacobsen, J. P.**, *Fra den danske oceanografiske Ekspedition til Middelhavet i Vinteren 1908—09.* Geografisk Tidskrift, Bd. 20. Köbenhavn 1910.
1898. **Schott, Gerhard**, *Weltkarte zur Übersicht der Meeresströmungen.* Deutsche Seewarte 1898.
1902. **Schott, Gerhard**, *Ozeanographie und maritime Meteorologie. Wissenschaftliche Ergebnisse der deutschen Tiefsee-Expedition auf dem Dampfer „Valdivia“ 1898—1899. Vol. I.* Jena 1902.
1898. **Supan, Alexander**, *Die jährlichen Niederschlagsmengen auf den Meeren.* Petermanns Geographische Mitteilungen 1898.
1874. **Thomson, C. Wyville**, *The Depths of the Sea.* 2nd ed. London 1874.
1877. **Thomson, C. Wyville**, *The Atlantic.* London 1877.
1898. **Thoulet, J.**, *Considérations sur la circulation océanique dans le Golfe de Gascogne.* *Comptes Rendus*, CXXVI, Paris 1898, p. 293.
1900. **Wegemann, Georg**, *Die Oberflächen-Strömungen des nordatlantischen Ozeans nördlich von 50° N.-Br.* Inaug.-Dissert. Altona 1900.
1910. **Witte, Emil**, *Aspiration infolge der Mischung von Wasser.* *Geographischer Anzeiger*, Oktober 1910, p. 223.

Explanation of the Plates.

- Pl. I. Chart showing the route of the Frithjof (July 6—20, 1910) with the observation-stations 1—48. The route of the Fram, with observation-stations, June 20—27 and July 4—7, 1910, is also given. Isobaths are drawn for 200, 500, 1000, 2000, 3000, and 4000 metres.
- Pl. II—VIII. Charts showing the horizontal distribution of Temperature and Salinity at depths of 0, 50, 100, 200, 300, 400, and 500 metres.
- Pl. IX. Section I of the Frithjof (Stats. 1—12, July 6—9, 1910), showing the vertical distribution of Temperature, Salinity, and, for depths greater than 1000 metres, also of Density (σ_t). Horizontal Scale 1:3,000,000. Vertical Scale 1:10,000. Broken lines represent Isotherms, unbroken lines Isohalines, and dotted lines represent Isopycnals. Black dots indicate observations with the Automatic Insulating Water-Bottle, rings observations with the Pettersson-Nansen Water-Bottle and a Nansen Thermometer, crosses observations with the stop-cock water-bottles (or in a few cases the Pettersson-Nansen Water-Bottle) and reversing thermometers.
- Pl. X. Section I, showing the vertical distribution of Temperature and Salinity to the depths of 1000 metres. Lines and marks indicate the same as in Pl. IX. Horizontal Scale 1:3,000,000. Vertical Scale 1:5,000.
- Pl. XI. Section I, showing the vertical distribution of Density (σ_t) to the depths of 1000 metres. The dotted lines represent Isopycnals. The marks indicate the same as in Pl. IX.
- Pl. XII. Section II of the Frithjof (Stats. 12—21, July 9—12, 1910), showing the vertical distribution of Temperature and Salinity. Lines and marks indicate the same as in Pl. IX. Horizontal Scale 1:3,000,000. Vertical Scale 1:5,000.
- Pl. XIII. Section II, showing the vertical distribution of Density (σ_t).
- Pl. XIV. Section III of the Frithjof (Stats. 22—35, July 16—18, 1910), showing the vertical distribution of Temperature and Salinity. Lines and marks indicate the same as in Pl. IX. Horizontal Scale 1:3,000,000. Vertical Scale 1:5,000.
- Pl. XV. Section III, showing the vertical distribution of Density (σ_t).
- Pl. XVI. Sections IV and V of the Frithjof (Stats. 35—48, July 18—20, 1910), showing the vertical distribution of Temperature and Salinity. Lines and marks indicate the same as in Pl. IX. Horizontal Scale 1:3,000,000. Vertical Scale 1:5,000.
- Pl. XVII. Sections IV and V, showing the vertical distribution of Density (σ_t).

— The Route of the Fridtjof, July, 1910.
 - - - The Route of the Fram, June and July, 1910. Scale = 1 : 9,000,000.

Fridtjof Nansen.

Verlag von Dr. Werner Klinkhardt, Leipzig.

— The Route of the Fridtjof, July 1910
 - - - The Route of the Fram, June and July 1910

Photolithogr. Julius Klinkhardt, Leipzig.

Scale 1:9,000,000

50 Metres

Fridthjof Nansen.

Verlag von Dr. Werner Klinkhardt, Leipzig.

Scale 1:9,000,000

1 mm. = 9 kilometres.

100 Metres

Photolithogr. Julius Klinkhardt, Leipzig.

— The Route of the Fridtjof, July 1910
 - - - The Route of the Fram, June and July 1910

Scale 1:9,000,000

200 Metres

Fridtjof Nansen.

— The Route of the Fridtjof, July 1910
 - - - The Route of the Fram, June and July 1910

Scale 1:9,000,000

300 Metres

Photolithogr. Julius Klinkhardt, Leipzig

Fridtjof Nansen.

Verlag von Dr. Werner Klinkhardt Leipzig.

Verlag von Dr. Werner Klinkhardt Leipzig.

Photolithogr. Julius Neukhardt, Leipzig.

Fridtjof Nansen.

Verlag von Dr. Werner Klinckschmidt, Leipzig.

Photol. Julius Klinckschmidt, Leipzig.

Section IV
39 38 37 36 35
19-VII 19-VII 19-VII 18-VII 18-VII
100 100 100 104 104 103
35-20 16 12 14 17 13

Fridtjof Nansen.

Section V

39 40 41 42 43 44 45 46 47 48
19-VII-10 19-VII-10 19-VII-10 19-VII-10 19-VII-10 19-VII-10 20-VII-10 20-VII-10 20-VII-10
100 35-20 98 20 101 17 102 16 103 13 104 14 105 13 106 10 107 9 108 8 109 7 110 6 111 5 112 4 113 3 114 2 115 1 116 0 117 -1 118 -2 119 -3 120 -4 121 -5 122 -6 123 -7 124 -8 125 -9 126 -10 127 -11 128 -12 129 -13 130 -14 131 -15 132 -16 133 -17 134 -18 135 -19 136 -20 137 -21 138 -22 139 -23 140 -24 141 -25 142 -26 143 -27 144 -28 145 -29 146 -30 147 -31 148 -32 149 -33 150 -34 151 -35 152 -36 153 -37 154 -38 155 -39 156 -40 157 -41 158 -42 159 -43 160 -44 161 -45 162 -46 163 -47 164 -48 165 -49 166 -50 167 -51 168 -52 169 -53 170 -54 171 -55 172 -56 173 -57 174 -58 175 -59 176 -60 177 -61 178 -62 179 -63 180 -64 181 -65 182 -66 183 -67 184 -68 185 -69 186 -70 187 -71 188 -72 189 -73 190 -74 191 -75 192 -76 193 -77 194 -78 195 -79 196 -80 197 -81 198 -82 199 -83 200 -84 201 -85 202 -86 203 -87 204 -88 205 -89 206 -90 207 -91 208 -92 209 -93 210 -94 211 -95 212 -96 213 -97 214 -98 215 -99 216 -100 217 -101 218 -102 219 -103 220 -104 221 -105 222 -106 223 -107 224 -108 225 -109 226 -110 227 -111 228 -112 229 -113 230 -114 231 -115 232 -116 233 -117 234 -118 235 -119 236 -120 237 -121 238 -122 239 -123 240 -124 241 -125 242 -126 243 -127 244 -128 245 -129 246 -130 247 -131 248 -132 249 -133 250 -134 251 -135 252 -136 253 -137 254 -138 255 -139 256 -140 257 -141 258 -142 259 -143 260 -144 261 -145 262 -146 263 -147 264 -148 265 -149 266 -150 267 -151 268 -152 269 -153 270 -154 271 -155 272 -156 273 -157 274 -158 275 -159 276 -160 277 -161 278 -162 279 -163 280 -164 281 -165 282 -166 283 -167 284 -168 285 -169 286 -170 287 -171 288 -172 289 -173 290 -174 291 -175 292 -176 293 -177 294 -178 295 -179 296 -180 297 -181 298 -182 299 -183 300 -184 301 -185 302 -186 303 -187 304 -188 305 -189 306 -190 307 -191 308 -192 309 -193 310 -194 311 -195 312 -196 313 -197 314 -198 315 -199 316 -200 317 -201 318 -202 319 -203 320 -204 321 -205 322 -206 323 -207 324 -208 325 -209 326 -210 327 -211 328 -212 329 -213 330 -214 331 -215 332 -216 333 -217 334 -218 335 -219 336 -220 337 -221 338 -222 339 -223 340 -224 341 -225 342 -226 343 -227 344 -228 345 -229 346 -230 347 -231 348 -232 349 -233 350 -234 351 -235 352 -236 353 -237 354 -238 355 -239 356 -240 357 -241 358 -242 359 -243 360 -244 361 -245 362 -246 363 -247 364 -248 365 -249 366 -250 367 -251 368 -252 369 -253 370 -254 371 -255 372 -256 373 -257 374 -258 375 -259 376 -260 377 -261 378 -262 379 -263 380 -264 381 -265 382 -266 383 -267 384 -268 385 -269 386 -270 387 -271 388 -272 389 -273 390 -274 391 -275 392 -276 393 -277 394 -278 395 -279 396 -280 397 -281 398 -282 399 -283 400 -284 401 -285 402 -286 403 -287 404 -288 405 -289 406 -290 407 -291 408 -292 409 -293 410 -294 411 -295 412 -296 413 -297 414 -298 415 -299 416 -300 417 -301 418 -302 419 -303 420 -304 421 -305 422 -306 423 -307 424 -308 425 -309 426 -310 427 -311 428 -312 429 -313 430 -314 431 -315 432 -316 433 -317 434 -318 435 -319 436 -320 437 -321 438 -322 439 -323 440 -324 441 -325 442 -326 443 -327 444 -328 445 -329 446 -330 447 -331 448 -332 449 -333 450 -334 451 -335 452 -336 453 -337 454 -338 455 -339 456 -340 457 -341 458 -342 459 -343 460 -344 461 -345 462 -346 463 -347 464 -348 465 -349 466 -350 467 -351 468 -352 469 -353 470 -354 471 -355 472 -356 473 -357 474 -358 475 -359 476 -360 477 -361 478 -362 479 -363 480 -364 481 -365 482 -366 483 -367 484 -368 485 -369 486 -370 487 -371 488 -372 489 -373 490 -374 491 -375 492 -376 493 -377 494 -378 495 -379 496 -380 497 -381 498 -382 499 -383 500 -384 501 -385 502 -386 503 -387 504 -388 505 -389 506 -390 507 -391 508 -392 509 -393 510 -394 511 -395 512 -396 513 -397 514 -398 515 -399 516 -400 517 -401 518 -402 519 -403 520 -404 521 -405 522 -406 523 -407 524 -408 525 -409 526 -410 527 -411 528 -412 529 -413 530 -414 531 -415 532 -416 533 -417 534 -418 535 -419 536 -420 537 -421 538 -422 539 -423 540 -424 541 -425 542 -426 543 -427 544 -428 545 -429 546 -430 547 -431 548 -432 549 -433 550 -434 551 -435 552 -436 553 -437 554 -438 555 -439 556 -440 557 -441 558 -442 559 -443 560 -444 561 -445 562 -446 563 -447 564 -448 565 -449 566 -450 567 -451 568 -452 569 -453 570 -454 571 -455 572 -456 573 -457 574 -458 575 -459 576 -460 577 -461 578 -462 579 -463 580 -464 581 -465 582 -466 583 -467 584 -468 585 -469 586 -470 587 -471 588 -472 589 -473 590 -474 591 -475 592 -476 593 -477 594 -478 595 -479 596 -480 597 -481 598 -482 599 -483 600 -484 601 -485 602 -486 603 -487 604 -488 605 -489 606 -490 607 -491 608 -492 609 -493 610 -494 611 -495 612 -496 613 -497 614 -498 615 -499 616 -500 617 -501 618 -502 619 -503 620 -504 621 -505 622 -506 623 -507 624 -508 625 -509 626 -510 627 -511 628 -512 629 -513 630 -514 631 -515 632 -516 633 -517 634 -518 635 -519 636 -520 637 -521 638 -522 639 -523 640 -524 641 -525 642 -526 643 -527 644 -528 645 -529 646 -530 647 -531 648 -532 649 -533 650 -534 651 -535 652 -536 653 -537 654 -538 655 -539 656 -540 657 -541 658 -542 659 -543 660 -544 661 -545 662 -546 663 -547 664 -548 665 -549 666 -550 667 -551 668 -552 669 -553 670 -554 671 -555 672 -556 673 -557 674 -558 675 -559 676 -560 677 -561 678 -562 679 -563 680 -564 681 -565 682 -566 683 -567 684 -568 685 -569 686 -570 687 -571 688 -572 689 -573 690 -574 691 -575 692 -576 693 -577 694 -578 695 -579 696 -580 697 -581 698 -582 699 -583 700 -584 701 -585 702 -586 703 -587 704 -588 705 -589 706 -590 707 -591 708 -592 709 -593 710 -594 711 -595 712 -596 713 -597 714 -598 715 -599 716 -600 717 -601 718 -602 719 -603 720 -604 721 -605 722 -606 723 -607 724 -608 725 -609 726 -610 727 -611 728 -612 729 -613 730 -614 731 -615 732 -616 733 -617 734 -618 735 -619 736 -620 737 -621 738 -622 739 -623 740 -624 741 -625 742 -626 743 -627 744 -628 745 -629 746 -630 747 -631 748 -632 749 -633 750 -634 751 -635 752 -636 753 -637 754 -638 755 -639 756 -640 757 -641 758 -642 759 -643 760 -644 761 -645 762 -646 763 -647 764 -648 765 -649 766 -650 767 -651 768 -652 769 -653 770 -654 771 -655 772 -656 773 -657 774 -658 775 -659 776 -660 777 -661 778 -662 779 -663 780 -664 781 -665 782 -666 783 -667 784 -668 785 -669 786 -670 787 -671 788 -672 789 -673 790 -674 791 -675 792 -676 793 -677 794 -678 795 -679 796 -680 797 -681 798 -682 799 -683 800 -684 801 -685 802 -686 803 -687 804 -688 805 -689 806 -690 807 -691 808 -692 809 -693 810 -694 811 -695 812 -696 813 -697 814 -698 815 -699 816 -700 817 -701 818 -702 819 -703 820 -704 821 -705 822 -706 823 -707 824 -708 825 -709 826 -710 827 -711 828 -712 829 -713 830 -714 831 -715 832 -716 833 -717 834 -718 835 -719 836 -720 837 -721 838 -722 839 -723 840 -724 841 -725 842 -726 843 -727 844 -728 845 -729 846 -730 847 -731 848 -732 849 -733 850 -734 851 -735 852 -736 853 -737 854 -738 855 -739 856 -740 857 -741 858 -742 859 -743 860 -744 861 -745 862 -746 863 -747 864 -748 865 -749 866 -750 867 -751 868 -752 869 -753 870 -754 871 -755 872 -756 873 -757 874 -758 875 -759 876 -760 877 -761 878 -762 879 -763 880 -764 881 -765 882 -766 883 -767 884 -768 885 -769 886 -770 887 -771 888 -772 889 -773 890 -774 891 -775 892 -776 893 -777 894 -778 895 -779 896 -780 897 -781 898 -782 899 -783 900 -784 901 -785 902 -786 903 -787 904 -788 905 -789 906 -790 907 -791 908 -792 909 -793 910 -794 911 -795 912 -796 913 -797 914 -798 915 -799 916 -800 917 -801 918 -802 919 -803 920 -804 921 -805 922 -806 923 -807 924 -808 925 -809 926 -810 927 -811 928 -812 929 -813 930 -814 931 -815 932 -816 933 -817 934 -818 935 -819 936 -820 937 -821 938 -822 939 -823 940 -824 941 -825 942 -826 943 -827 944 -828 945 -829 946 -830 947 -831 948 -832 949 -833 950 -834 951 -835 952 -836 953 -837 954 -838 955 -839 956 -840 957 -841 958 -842 959 -843 960 -844 961 -845 962 -846 963 -847 964 -848 965 -849 966 -850 967 -851 968 -852 969 -853 970 -854 971 -855 972 -856 973 -857 974 -858 975 -859 976 -860 977 -861 978 -862 979 -863 980 -864 981 -865 982 -866 983 -867 984 -868 985 -869 986 -870 987 -871 988 -872 989 -873 990 -874 991 -875 992 -876 993 -877 994 -878 995 -879 996 -880 997 -881 998 -882 999 -883 1000 -884 1001 -885 1002 -886 1003 -887 1004 -888 1005 -889 1006 -890 1007 -891 1008 -892 1009 -893 1010 -894 1011 -895 1012 -896 1013 -897 1014 -898 1015 -899 1016 -900 1017 -901 1018 -902 1019 -903 1020 -904 1021 -905 1022 -906 1023 -907 1024 -908 1025 -909 1026 -910 1027 -911 1028 -912 1029 -913 1030 -914 1031 -915 1032 -916 1033 -917 1034 -918 1035 -919 1036 -920 1037 -921 1038 -922 1039 -923 1040 -924 1041 -925 1042 -926 1043 -927 1044 -928 1045 -929 1046 -930 1047 -931 1048 -932 1049 -933 1050 -934 1051 -935 1052 -936 1053 -937 1054 -938 1055 -939 1056 -940 1057 -941 1058 -942 1059 -943 1060 -944 1061 -945 1062 -946 1063 -947 1064 -948 1065 -949 1066 -950 1067 -951 1068 -952 1069 -953 1070 -954 1071 -955 1072 -956 1073 -957 1074 -958 1075 -959 1076 -960 1077 -961 1078 -962 1079 -963 1080 -964 1081 -965 1082 -966 1083 -967 1084 -968 1085 -969 1086 -970 1087 -971 1088 -972 1089 -973 1090 -974 1091 -975 1092 -976 1093 -977 1094 -978 1095 -979 1096 -980 1097 -981 1098 -982 1099 -983 1100 -984 1101 -985 1102 -986 1103 -987 1104 -988 1105 -989 1106 -990 1107 -991 1108 -992 1109 -993 1110 -994 1111 -995 1112 -996 1113 -997 1114 -998 1115 -999 1116 -1000 1117 -1001 1118 -1002 1119 -1003 1120 -1004 1121 -1005 1122 -1006 1123 -1007 1124 -1008 1125 -1009 1126 -1010 1127 -1011 1128 -1012 1129 -1013 1130 -1014 1131 -1015 1132 -1016 1133 -1017 1134 -1018 1135 -1019 1136 -1020 1137 -1021 1138 -1022 1139 -1023 1140 -1024 1141 -1025 1142 -1026 1143 -1027 1144 -1028 1145 -1029 1146 -1030 1147 -1031 1148 -1032 1149 -1033 1150 -1034 1151 -1035 1152 -1036 1153 -1037 1154 -1038 1155 -1039 1156 -1040 1157 -1041 1158 -1042 1159 -1043 1160 -1044 1161 -1045 1162 -1046 1163 -1047 1164 -1048 1165 -1049 1166 -1050 1167 -1051 1168 -1052 1169 -1053 1170 -1054 1171 -1055 1172 -1056 1173 -1057 1174 -1058 1175 -1059 1176 -1060 1177 -1061 1178 -1062 1179 -1063 1180 -1064 1181 -1065 1182 -1066 1183 -1067 1184 -1068 1185 -1069 1186 -1070 1187 -1071 1188 -1072 1189 -1073 1190 -1074 1191 -1075 1192 -1076 1193 -1077 1194 -1078 1195 -1079 1196 -1080 1197 -1081 1198 -1082 1199 -1083 1200 -1084 1201 -1085 1202 -1086 1203 -1087 1204 -1088 1205 -1089 1206 -1090 1207 -1091 1208 -1092 1209 -1093 1210 -1094 1211 -1095 1212 -1096 1213 -1097 1214 -1098 1215 -1099 1216 -1100 1217 -1101 1218 -1102 1219 -1103 1220 -1104 1221 -1105 1222 -1106 1223 -1107 1224 -1108 1225 -1109 1226 -1110 1227 -1111 1228 -1112 1229 -1113 1230 -1114 1231 -1115 1232 -1116 1233 -1117 1234 -1118 1235 -1119 1236 -1120 1237 -1121 1238 -1122 1239 -1123 1240 -1124 1241 -1125 1242 -1126 1243 -1127 1244 -1128 1245 -1129 1246 -1130 1247 -1131 1248 -1132 1249 -1133 1250 -1134 1251 -1135 1252 -1136 1253 -1137 1254 -1138 1255 -1139 1256 -1140 1257 -1141 1258 -1142 1259 -1143 1260 -1144 1261 -1145 1262 -1146 1263 -1147 1264 -1148 1265 -1149 1266 -1150 1267 -1151 1268 -1152 1269 -1153 1270 -1154 1271 -1155 1272 -1156 1273 -1157 1274 -1158 1275 -1159 1276 -1160 1277 -1161 1278 -1162 1279 -1163 1280 -1164 1281 -1165 1282 -1166 1283 -1167 1284 -1168 1285 -1169 1286 -1170 1287 -1171 1288 -1172 1289 -1173 1290 -1174 1291 -1175 1292 -1176 1293 -1177 1294 -1178 1295 -1179 1296 -1180 1297 -1181 1298 -1182 1299 -1183 1300 -1184 1301 -1185 1302 -1186 1303 -1187 1304 -1188 1305 -1189 1306 -1190 1307 -1191 1308 -1192 1309 -1193 1310 -1194 1311 -1195 1312 -1196 1313 -1197 1314 -1198 1315 -1199 1316 -1200 1317 -1201 1318 -1202 1319 -1203 1320 -1204 1321 -1205 1322 -1206 1323 -1207 1324 -1208 1325 -1209 1326 -1210 1327 -1211 1328 -1212 1329 -1213 1330 -1214 1331 -1215 1332 -1216 1333 -1217 1334 -1218 1335 -1219 1336 -1220 1337 -1221 1338 -1222 1339 -1223 1340 -1224 1341 -1225 1342 -1226 1343 -1227 1344 -1228 1345 -1229 1346 -1230 1347 -1231 1348 -1232 1349 -1233 1350 -1234 1351 -1235 1352 -1236 1353 -1237 1354 -1238 1355 -1239 1356 -1240 1357 -1241 1358 -1242 1359 -1243 1360 -1244 1361 -1245 1362 -1246 1363 -1247 1364 -1248 1365 -1249 1366 -1250 1367 -1251 1368 -1252 1369 -1253 1370 -1254 1371 -1255 1372 -1256 1373 -1257 1374 -1258 1375 -1259 1376 -1260 1377 -1261 1378 -1262 1379 -1263 1380 -1264 1381 -1265 1382 -1266 1383 -1267 1384 -1268 1385 -1269 1386 -1270 1387 -1271 1388 -1272 1389 -1273 1390 -1274 1391 -1275 1392 -1276 1393 -1277 1394 -1278 1395 -1279 1396 -1280 1397 -1281 1398 -1282 1399 -1283 1400 -1284 1401 -1285 1402 -1286 1403 -1287 1404 -1288 1405 -1289 1406 -1290 1407 -1291 1408 -1292 1409 -1293 1410 -1294 1411 -1295 1412 -1296 1413 -1297 1414 -1298 1415 -1299 1416 -1300 1417 -1301 1418 -1302 1419 -1303 1420 -1304 1421 -1305 1422 -1306 1423 -1307 1424 -1308 1425 -1309 1426 -1310 1427 -1311 1428 -1312 1429 -1313 1430 -1314 1431 -1315 1432 -1316 1433 -1317 1434 -1318 1435 -1319 1436 -1320 1437 -1321 1438 -1322 1439 -1323 1440 -1324 1441 -1325 1442 -1326 1443 -1327 1444 -1328 1445 -1329 1446 -1330 1447 -1331 1448 -1332 1449 -1333 1450 -1334 1451 -1335 1452 -1336 1453 -1337 1454 -1338 1455 -1339 1456 -1340 1457 -1341 1458 -1342 1459 -1343 1460 -1344 1461 -1345 1462 -1346 1463 -1347 1464 -1348 1465 -1349 1466 -1350 1467 -1351 1468 -1352 1469 -1353 1470 -1354 1471 -1355 1472 -1356 1473 -1357 1474 -1358 1475 -1359 1476 -1360 1477 -1361 1478 -1362 1479

Section IV

Fridtjof Nansen.

Section V

Verlagsges. Julius Klinkhardt, Leipzig.

GC
491
N36

Nansen, Fridtjof
The waters of the
north-eastern North Atlantic

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY

UTL AT DOWNSVIEW

D RANGE BAY SHLF POS ITEM C
39 13 07 15 12 018 4