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THE NORWEGIAN SEA

ITS PHYSICAL OCEANOGRAPHY

BASED UPON THE NORWEGIAN RESEARCHES 1900—1904

BY

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(WITH 28 PLATES)

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Preface.

In the present memoir on the Physical Oceanography of the Norwegian Sea we have described the results of the Norwegian investigations made in this sea area, chiefly with the *Michael Sars*, during the five years of 1900 to 1904. We have also to some extent made use of the observations taken in the southern Norwegian Sea in May, 1905, and the current-measurements made in recent years (1906 & 1908). The other observations taken since 1904, are of less importance for our discussions in the present work, as they were chiefly taken in the coast waters for other purposes.

The original plan of the work was that Nansen, who organized and led the physical part of the investigations in 1900, should have written a report on the results of the researches of that first year, while Helland-Hansen, who has had charge of the physical investigations since 1900, should have written separate reports on the results of the following years. Nansen [1901] wrote a preliminary account of the researches in 1900, and also began the preparation of his final report; but owing to other pressing work he was for some time prevented from finishing it. In the mean while a much greater and very important observation-material had been collected during the continued researches of the succeeding years. By these later observations the results of the first year were essentially completed, and were even altered on many important points. Helland-Hansen was much occupied with the continuous investigations and with other work, so that he could not commence his report until 1904.

Under these circumstances we considered it preferable to unite our efforts, and we therefore agreed to work up together the whole observation-material into one memoir, which would give a more complete description of the oceanography of the Norwegian Sea. Other work, and various circumstances, have, however, hindered us from finishing this memoir until now. The different parts of it have been written at various periods since 1902, and it is therefore possible that several recent publications have not been duly considered by us, because our manuscript had been written before they appeared. But wherever it was possible we have tried to add notes referring to later publications of importance. We may also mention that our Plates II—XXIVA were printed in 1905. The final discussion of the observations has since led us to views and conclusions that, as regards several details, made an alteration of some figures in the Plates desirable; but in the text we have called attention to alterations of this kind, which we considered to be important.

Although the report which we now publish may seem voluminous, it is not as detailed on many points as we think that it ought to have been, if time had permitted. There are even several questions of interest, which we have hardly been able to mention, as we had to confine ourselves to the main features.

We hope, however, that we are not too immodest, if we say that the great observation-material at our disposal has led us to a number of discoveries, which are important in several respects, and which give great promise for the future. We may mention the new views on the movements of the water in the sea mentioned in Chapters VI, VII, VIII, IX, and X, the discovery of the formation, distribution, and uniformity of the bottom-water, Chap. XI, etc. But of more general interest are perhaps the annual variations in the currents (the Atlantic Current, Chap. VII, and the Coast Current, Chap. VIII), and their relations to the variations in the climate of Norway, the variations in the fisheries, and also the variations in the harvests of Norway, the growth of the forests, etc. We have also been able to trace a certain relation between these variations and cosmic causes. We think that these discoveries give us the right to hope that by continued investigations it will be possible to predict the character of climate, fisheries, and harvests, months or even years in advance.

There is here a great field for future investigation into which we wish that time would have allowed us to go more fully; but we have been obliged to confine ourselves at present to laying down the main lines and pointing out briefly certain great features, while we have retained the more detailed investigations for special works on the relation between the Hydrosphere and the Atmosphere, and on the relation between oceanic currents and biological conditions, which we hope to publish in a near future.

The observations which we now publish have for the most part been collected during the cruises of the *Michael Sars*(1); valuable material has also been collected during the cruises of the *Heimdal*, of the Royal Norwegian Navy, in May, 1901 and 1902, and the fishery-steamer *Ask* in November, 1903. A great number of surface-observations have been sent in by captains of sealing-vessels, *viz*: Fr. Svendsen *(Hvidfisken)*, Ingvald Svendsen *(Hvidfisken* and *Jasai)*, P. Chr. Isaksen *(Tora den Blide)*, and H. Andresen *(Rivalen)*, of Tromsö; Chr. Larsen *(Urania)*, of Aalesund; Haueland *(Egil)*, of Bergen; J. Nilsen *(Aksel*, and *Kvik)*, A. Marcussen *(Hekla*, and *Vega)*, A. Stökken *(Capella)* and A. B. Abrahamsen *(Fortuna)*, of Sandefjord.

In mentioning those who have assisted us in our work we naturally first of all wish to express our gratitude to Dr. Johan Hjort, the able leader of the Norwegian Marine and Fishery Researches, who with intelligent interest, has always assisted us in every way, and to whose enterprise and initiative these investigations are due in the first instance.

We also thank Dr. D. Damas, Professor Dr. H. H. Gran, Mr. E. Koefoed, Mr. A. M. Schweigaard, and Mr. Herbert E. W. Levin for their valuable assistance in collecting observations during several cruises.

We wish also to tender special thanks to the captains of the ships:

Mr. G. Sørensen, and Mr. Thor Iversen, masters of the *Michael Sars*, Capt. Burchhardt, and Capt. Tryggve Holst, who commanded the *Heimdal* on the cruises in 1901, and 1902, and Mr. Kjærstad,

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(1) The names of those who have taken the observations and collected the water-samples are mentioned in our Tables II and III.

master of the *Ask*. By the able way in which they have navigated their ships, and the great interest with which they have furthered the investigations, they have an important share in the results.

Finally we wish to thank the masters of the sealing-vessels, mentioned above, for the valuable assistance they have given us, by collecting observations and water-samples from the Arctic regions, which have been of great importance for our discussion.

We have previously made a great many communications about our investigations and some of their results. Summaries of the investigations have been given for each year in the Annual Report of the Norwegian Fishery Investigations ("Aarsberetning vedkommende Norges fiskerier", published by the Director of the Fisheries, Bergen). In 1901 Nansen gave a preliminary account of some results of the cruise in 1900. Dr. Hjort [1901] wrote a paper in *Petermann's geographische Mitteilungen*, and he has also made communications in several papers, and given lectures, *e. g.* at the meetings of the International Council for the Study of the Sea, in "Institut für Meereskunde" in Berlin etc. Helland-Hansen, every year since 1903, has given lectures at the International Courses on Oceanic Research, in Bergen, where our results have been described; he read a paper before the Hydrographical Congress in Copenhagen in 1904 [1904]. He wrote a summary in Dr. Hjort's book "Norsk Havfiske" [1905], and he has made communications about our work at the meetings of the International Council for the Study of the Sea in Amsterdam (1906) and London (1907). Nansen also made communications regarding our results at the meeting of the Royal Geographical Society, when the International Council was in London in 1907. In January, 1906, we sent a summary on our investigations ("Die norwegischen hydrographischen Untersuchungen im Nordmeere", von Fridtjof Nansen und B. Helland-Hansen, printed as manuscript, and accompanied by our Plates II—XXIV B) to the members of the International Council at their meeting in Amsterdam.

In his paper on "Northern Waters" [1906] describing Amundsen's oceanographic observations in 1901, Nansen has also mentioned some results of our investigations; and in a paper of 1907, Helland-Hansen has described his current-measurements in 1906.

The station-observations made since August, 1902, have been published in the *Bulletin*, edited by the International Bureau for the Study of the Sea.

Owing to these earlier communications, many points which are discussed in the present report have already been mentioned in the literature by several oceanographers. We may mention, for instance, the vortex-movements and the cyclonic circulation-systems in the Norwegian Sea, the vertical oscillations (and boundary waves) of the intermediate strata, etc. We have not until now, however, had an opportunity of giving a full and complete description of our views, and have not been able to duly consider the use that has already been made of our earlier communications.

April, 1909.

Björn Helland-Hansen. Fridtjof Nansen.

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1. History of the Exploration of the Norwegian Sea.

A great part of the coasts and surface of the Norwegian Sea, extending between Norway, the Færoes, Iceland, Greenland and Spitsbergen, had already been explored eight hundred or a thousand years ago by the Norsemen; but what was hidden under the surface of this sea-basin had remained practically a more or less unknown world until the *Norwegian North Atlantic Expedition* started on board the *Vöringen* in 1876. The little that was known about its Depths and Physical Oceanography before that day, was chiefly based upon more or less accidental observations, taken by expeditions that had happened to cross this sea in pursuit of other objects; and as the instruments and methods of research were imperfect the observations were, to a great extent, of doubtful value. Certain general features of the depths, chiefly near its edges, and the physical conditions, chiefly near the surface, *e. g.* the warm Atlantic Current (Gulf Stream) on the Norwegian Side, and the cold Polar Current on the Greenland side etc., had been traced out; but the exploration-work on which our present knowledge of this sea is based, and which has made it the only fairly well known part of the Ocean, has all of it been carried out since 1876.

Amongst the expeditions before that date, the following may be mentioned.

Expeditions before 1876.

The two chief features of the circulation of the Norwegian Sea, *viz.* the warm Atlantic Current and the cold Polar Current, have evidently been recognized very early. Already the old Norsemen realized the existence of the Polar Current, carrying great ice masses southwards along the western side of the Norwegian Sea along the Greenland coast; and in the "Konung's Skuggsjá" (Speculum Regale) of the 13th century, a graphic description is given of this drifting ice.

The first explorer who is mentioned in literature as having actually discovered the Atlantic Current ("Gulf Stream") entering the Norwegian Sea, is MARTIN FROBISHER, who on his third voyage, in 1578, in the Atlantic, north-west from Ireland, met "with a great currante from oute of the south-west, which carryed us (by our reckoning) one point to the north-estwardes of our said course, which currant seemed to us to continue itselfe towards Norway and other the north-east partes of the world." This current was assumed to be "the same whiche the Portugalles meete at Capo d'Buona Speranza", and which runs "into the greate Bay of Mexico, where, also having a let of lande it is forced to strike backe agayne towardes the north-east" [COLLINSON 1867, p. 232].

The North Polar expedition on board the *Racehorse* and the *Carcass*, under the command of JOHN PHIPPS (Lord MULGRAVE), sailed from England across the Norwegian Sea to Spitsbergen and the Seven Islands and back in 1773. During this voyage, Dr. IRVING made the first primitive attempts to take deep-sea temperatures in the Norwegian Sea down to 780 fathoms, and also to determine the specific gravity of the water-strata [PHIPPS, 1774, pp. 141—147]. On Aug. 31, 1773, he found, in 68° 47′ N. Lat., and about 3° 24′ E. Long., a temperature of 0° C. (32° Fahr.) at a depth of 673 fathoms (1226 metres) which is very nearly correct. But on June 20, 1773, in 67° 5′ N. Lat. and about 0° 50′ W. Long., he found by the same instrument (Lord CAVENDISH's thermometer) —3·3° C. (26° Fahr.) in 780 fathoms (1426 metres), which is nearly 3° C. too low. On Sept. 4, 1773, in 65° N. Lat., and about 2° E. Long., Dr. IRVING found, by an insulated water-bottle of his own construction, a temperature of 4·4° C. (40° Fahr.) at the bottom in 683 fathoms (1249 metres), which is about 5·5° C. too high.

This last sounding brought up a bottom-sample of blue clay, and it is the first sounding on record, to reach the bottom of the deep sea.

Between 1806 and 1822, J. SCORESBY and his son W. SCORESBY made a number of cruises in the northern Norwegian Sea, chiefly for whaling, which resulted in a book by the latter about the Arctic Seas [1820], which is a standard work for its time, and contains much new and valuable information about the northern Norwegian Sea, its currents, ice, etc. His description of the East Greenland Polar Current, and the formation, distribution, and movements of its ice, is especially valuable. His deep-sea temperatures are much too high, owing to the imperfect instruments (a kind of insulated water-bottle) of that time (*e. g.* 2·8° C. and 3·3° C. at 1335 and 1392 metres in 79° and 78° N. Lat.).

In 1818 the expedition on board the *Dorothea* and the *Trent*, under Captain DAVID BUCHAN and Lieutenant JOHN FRANKLIN, sailed from England to Spitsbergen and the sea between Spitsbergen and Greenland. Some observations on deep-sea temperatures (very imperfect), currents, and the distribution of ice were made [BEECHEY, 1843].

On his famous North Polar expedition on board the *Hecla*, in 1827, Sir EDWARD PARRY took obervations of the surface-temperature of the Norwegian Sea and the Spitsbergen Sea, and also made some determinations of the temperature and specific gravity below the surface (at moderate depths) of the latter [PARRY, 1828].

During the French expedition on board *La Recherche*, in 1838 and 1839, to Norway and Spitsbergen, observations of the temperatures of the sea were made by BRAVAIS and MARTINS [1839].

In 1860 the expedition on board the *Bulldog* under the command of Sir LEOPOLD M'CLINTOCK, took soundings and temperature-observations in the sea between the Færoes, Iceland and Greenland, with the view of examining the possibility of carrying a telegraph-cable via this route to America. The first valuable soundings on the ridge between the Færoes and Iceland were then taken.

In an interesting paper, of 1861, Admiral C. IRMINGER of the Royal Danish Navy, discussed the currents round Iceland His conclusions were based on the observations of surface-temperatures and drift, collected yearly by vessels sailing to Iceland and Greenland. He pointed out that a warm Atlantic Current runs north-west and northwards along the south-west and west coast of Iceland, whilst a cold current, carrying ice — the East Greenland Polar Current — runs southwards on the other side of the Denmark Strait. He also pointed out that a branch of the Greenland Polar Current runs eastwards, north and east of Iceland [see 1843, 1853, 1861, 1870]. In this connection it may also be mentioned that another Dane, Professor COLDING [1870], who in his view of oceanic circulation was much ahead of his time, held the view that Irminger's warm current gradually turned westwards, west of Iceland, and then south-westwards with the Greenland Polar Current; while PETERMANN [1870] thought that it ran towards the north-east and east round the north coast of Iceland. Later observations have proved that both views are correct, as the current divides; but it is the greater branch that runs towards the west and south-west as assumed by COLDING.

During the Swedish expeditions to Spitsbergen and the northern seas, in 1858 under the leadership of O. TORELL, and in 1861, 1863—1864, 1868 and 1872—1873 under the leadership of A. E. NORDENSKIÖLD, oceanographic observations of various kinds were made. An especially important expedition in this respect was that of 1868, on board the *Sofia*, during which many soundings and temperature observations were taken [FRIES and NYSTRÖM, 1870]. Very great depths, of as much as 4846 metres (2650 fathoms), were supposed to have been discovered west of Spitsbergen, forming the so-called "Swedish Deep"; but the Swedish expedition under NATHORST, in 1898, found that this deep hollow does not exist; the deep sounding of 1868 must have been a mistake due to imperfect methods.

In 1868 and 1869, two German expeditions were made in the *Albert* and the *Bienenkorb*, by BESSELS and DORST, to the Spitsbergen waters. Observations on sea-temperature and the distribution of ice were collected [DORST, 1877].

During the German North Polar expeditions under the leadership of Captain KOLDEWEY, on board the *Germania* in 1868 (to the sea between Norway, Greenland and Spitsbergen), and on board the *Germania* and *Hansa* to East Greenland in 1869—1870 [1873], valuable soundings and temperature-observations were taken, especially in the region of the East Greenland Polar Current.

The *Lightning* Expedition, in 1868, under the scientific leadership of Sir WYVILLE THOMSON and Dr. WILL. B. CARPENTER, was the first

English scientific deep-sea expedition. The sea between the Hebrides and the Færoes, forming the real entrance to the Norwegian Sea, was investigated, and the Færoe-Shetland Channel was discovered and explored. Some important observations on the relation between animal life and deep-sea temperatures were made, and a distinction was drawn between a cold deep-sea area of Arctic origin and a warm area of Atlantic nature.

This important expedition was followed by another on board the *Porcupine* (Capt. CALVERT) in 1869, under the same scientific leaders. Two cruises were made west and south of Iceland, whilst the third cruise explored the sea between the Hebrides, the Shetlands, and the Færoes. The Færoe-Shetland Channel was explored, and important observations of the deep-sea temperatures were made. In the "cold area" of this deep channel, between 60° and 62° N. Lat., bottom-temperatures of —0·7° C. and —1·3° C. were observed in 900 and 1100 metres; whilst in the "warm area", south of 60° N. Lat., and separated from the latter by a ridge, bottom-temperatures of 7·9° C. in 650 metres, and between 5·9° and 5·2° C. in 1300—1400 metres, were observed [1870].

During a cruise, in 1871, to the sea on the western side of Spitsbergen (between 73½° and 81° 20′ N. Lat.), LEIGH SMITH made observations of deep-sea temperatures, and found unexpectedly high temperatures in the upper water-strata, which might indicate a warm current off the west coast of Spitsbergen. In a depth of 457 metres, in 73° 27′ N. Lat. and 20° 21′ E. Long., he observed a bottom-temperature above zero Centigrade (0·6 ° C.)

During the expeditions of the *Isbjörn* under the command of WEYPRECHT [1871, pp. 457—463] and Count WILCZEK, in 1871 and 1872, important observations of depths and deep-sea temperatures were made in the sea between Norway, Bear Island, and Spitsbergen, and it was discovered that the bottom-water of this shallow sea might have temperatures above 0° C. as far north as between 71° and 75° N. Lat. West of southern Spitsbergen a warm surface-layer, 400 metres deep, was observed, whilst the bottom-temperature at 457 metres was —0·7° C. Many oceanographic observations were made in the Barents Sea during these two expeditions, as well as during the *Teget-*

thoff Expedition, in 1872—1874 [WEYPRECHT, 1874, pp. 65, *et seq.* and 1878, pp. 345 *et seq.*].

Through the yearly cruises of the Norwegian surveying-vessel, *Hansteen*, after 1867, as also through the Norwegian Coast Survey before that time, the chief bathymetrical features of the sea off the Norwegian coast gradually became known; and by British and Danish soundings, the chief bathymetrical features of the sea near the Shetlands, round the Færoes, and Iceland, had also during this time been studied.

It should be added that since 1869, on Prof. MOHN's initiative, captains of Norwegian sealing-vessels have yearly made temperature-observations in the Norwegian Sea and the Spitsbergen waters (as also in the Barents and Kara Seas), and valuable observation-material has thus been collected.

On a voyage to Greenland in 1875, Prof. AMUND HELLAND made observations of the amount of chlorine in the surface-water of the northern North Sea, and the southern Norwegian Sea [1876].

Period 1876—1900.

The above-mentioned explorations, before 1876, had been confined almost entirely to the outskirts of the Norwegian Sea, *e. g.* the sea between Scotland and the Færoes, near the east coast of Greenland, the sea between Spitsbergen and Norway, and the sea off the Norwegian coast. But the Norwegian Sea itself, with its deep basins, its temperatures, salinities, and currents, was still practically a *mare incognitum*, when the Norwegian *Vöringen* Expedition began its work under the scientific leadership of Prof. H. MOHN and Prof. G. O. SARS. The work was carried on during three summers (1876—1878), and 375 Stations with deep-sea soundings were taken in all parts of the sea between Norway, the Færoes, Iceland, Jan Mayen, Spitsbergen (as far north as 80° N. Lat.), Bear Island, and Finmark. The oceanographic results of this pioneer-expedition are chiefly recorded in MOHN's important Memoir on the "North Ocean" (the Norwegian Sea) revealing the principal, hitherto unknown bathymetrical features of the Norwegian Sea Basin [MOHN, 1877; 1878; 1887; see also TORNÖE, 1883, and SCHMELCK, 1881]. The leading features of the vertical and horizontal distribution of temperature in this sea were also clearly demonstrated. The deep-sea thermometers, however, were at that time still very imperfect, and it was only in the last year, 1878, of the expedition that the NEGRETTI & ZAMBRA Reversing Thermometer was introduced. This thermometer marks a great improvement in oceanographic research; but unfortunately the reversing arrangement (a wooden case) used during the cruise of the *Vöringen*, in 1878, was not satisfactory [cf. NANSEN, 1906, p. 58], and therefore the deep-sea observations taken with this instrument were not as good as they otherwise might have been. But considering the imperfect instruments at MOHN's disposal, it must be acknowledged that his temperatures are on the whole remarkably good. His observations of the temperature of the bottom-water can be very easily controlled, as this water has a very uniform temperature (see later). They have a marked tendency to be too low, especially in the sea south and south-east of Jan Mayen, and in the northern part of the Norwegian Sea, where his final values are even as much as 0.3° C. (Stat. 302) too low. These errors have led him, for instance, into the mistake of believing that the bottom-temperatures should be lowest under the East Greenland Polar Current (cf. his map of the Temperature of the Sea at the Bottom *op. cit.* 1887, Pl. XXV.)

Owing to the imperfect methods of the time, the determinations of the specific gravity and the salinity of the sea-water were not sufficiently accurate, and by computing the densities from these determinations MOHN has arrived at misleading results as to the horizontal and vertical distribution of the density of the Norwegian Sea,

MOHN's discussion of his results and of the circulation of the Norwegian Sea is the first attempt to adopt a wholly mathematical method for the calculation of oceanic circulation; and it marks the beginning of a new era in Physical Oceanography. But as his discussions are based upon imperfect observation-material, it is not to be expected that the results would be very correct. He has, however, found certain great features in the circulation of the surface-layers which are of importance. The difference between his system of circula-

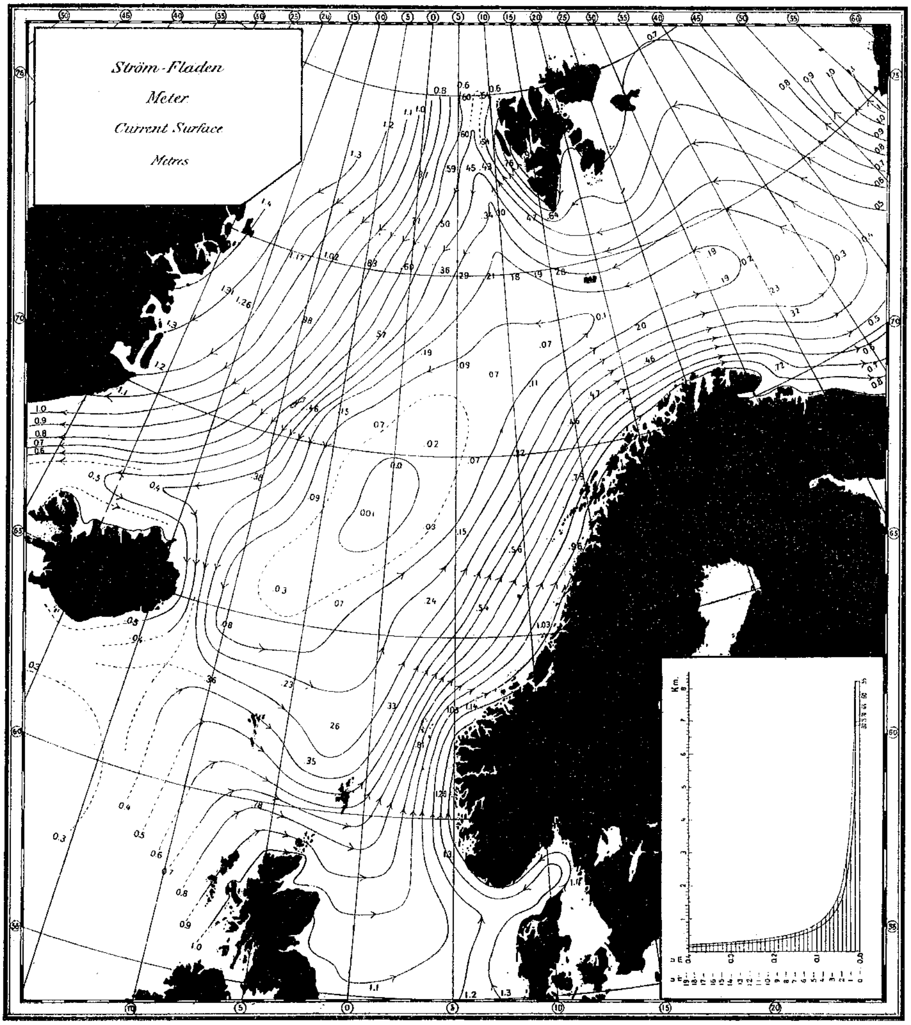

Fig. 1. The Circulation of the Norwegian Sea as represented by MOHN [1887, Pl. XLIII].

tion and the views our observations have led us to, is best seen by a comparison of his map of the currents (Fig. 1), with our figure of the circulation (Fig. 2).

For his discussion of the surface of the Norwegian Sea, MOHN had also a great number of surface-temperature observations, which, by his arrangement, had been collected yearly by Norwegian sealers on their voyages to the Arctic regions, as already mentioned.

In the summers of 1877, 1878, and 1879, some important cruises

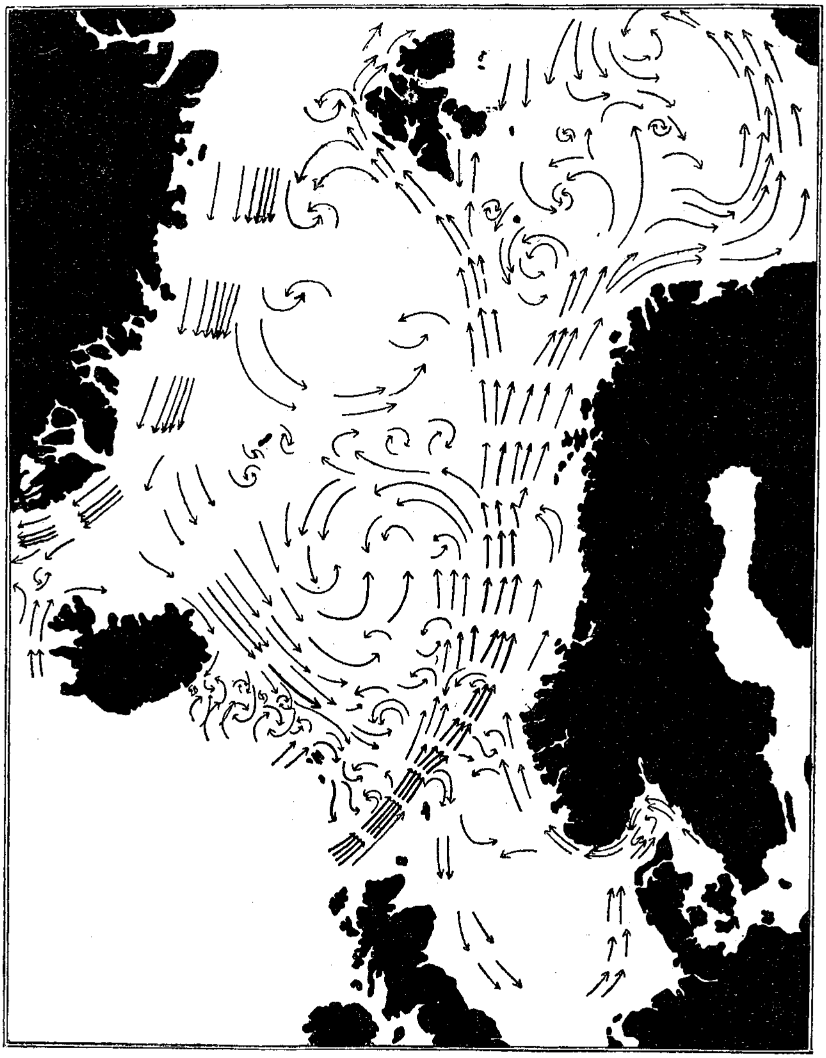

Fig. 2. The Circulation of the Nowegian Sea, according to our observations.

were made in Denmark Strait, by the *Fylla* and the *Ingolf* of the Royal Danish Navy, under the command of Captains Jacobsen, 1877, Buchwald, 1878, and Mourier, 1879. The observations were taken by Lieutenants Caroc, Bardenfleth, and Wandel(1). During these expeditions a great many soundings and vertical series of temperatures were taken in the sea between Iceland and Greenland, and

(1) See Hoffmeyer, [1878, pp. 88—98], Bardenfleth, [1879, pp. 42—47] and Mourier, [1880, pp. 47—60].

north of Iceland. The existence of the suboceanic ridge between Iceland and Greenland was etablished. The depth of the warm waters of the Irminger Current, off the western Icelandic coast, was determined, and its eastward continuation round the north coast, was traced. The cold bottom-water, as well as the cold, Polar surface-layers overlying warmer water, were observed in Denmark Strait and in the sea north of Iceland. The lowest values that were found for the temperature of the bottom-water are, however, too low (— 1·8° and — 1·9° C.)

During NORDENSKIÖLD's famous *Vega* Expedition round Asia, in 1878—1879, and the Dutch *Willem Barendsz* Expeditions in the summers of 1878—1882, under command of Lieutenants de BRUIJNE and v. BROCKHUIJZEN, valuable oceanographic observations were made in the Barents Sea, which are not, however, of direct importance for a knowledge of the Norwegian Sea.

The expedition on board the *Knight Errant*, under Staff-Commander TIZARD, in 1880, explored the Færoe-Shetland Channel and the Wyville Thomson Ridge [TIZARD and MURRAY, 1880; 1881—82].

These explorations were continued in 1882, during the expedition in the *Triton*, of the British Royal Navy, with Sir JOHN MURRAY [1882; 1883, p. 612] as scientific leader. Numerous soundings and physical observations were taken, especially on the Wyville Thomson Ridge and on both sides of it towards the deep sea.

By the two last-mentioned expeditions the existence of the Wyville Thomson Ridge, was finally settled, and its configuration and physical conditions traced out. Thus it was finally proved that Europe (Scotland) is connected with Greenland by a continuous suboceanic ridge extending from Scotland to the Færoe Bank (see fig. 8), from the Færoes to Iceland, thence across Denmark Strait to Greenland. The saddle-depths of the ridge hardly exceed 550 metres (300 fathoms). By this ridge, the deeper parts of the Norwegian Sea Basin are entirely shut off from those of the Atlantic, and the cold bottom-water of the former is prevented from running into the latter. The existence of this ridge is a feature of vital importance for the entire circulation of the Norwegian Sea. It forms a barrier to the movements of the water-masses, even those of the surface, as will be mentioned later;

and its depths regulate the depths of the few currents coming in and running out from this basin.

During NORDENSKIÖLD's expedition in the *Sofia*, to Greenland, in the summer of 1883, Dr. AXEL HAMBERG [1884; 1885] took several vertical series of observations in the region of the Polar Current along the east coast of Greenland, south of the Iceland-Greenland Ridge. His six vertical series of temperatures (Stats. 4, and 61—65, *l. c.*, pp. 12 & 13) and some salinities, off the coast north of 65° N. Lat., in connection with a few observation-stations of the *Ingolf* expedition, form the only known material that affords an idea of the volume and physical conditions of this branch of the Greenland Polar Current, running out of the Norwegian Sea Basin. Under the waters of the Polar coast-current, HAMBERG found warm water, which he assumed to be a continuation of the Irminger Current. His deep-sea temperatures were taken with the NEGRETTI & ZAMBRA Reversing Thermometer, and a reversing arrangement of his own construction. They may therefore be expected to be very trustworthy.

In 1891—1892 captain C. RYDER, of the Danish Royal Navy, made his expedition in the *Hekla* to the northern east coast of Greenland, and took a number of soundings and vertical series of temperatures in the sea between Iceland, Jan Mayen, and Greenland, and in the sea east of Greenland between 74° and 76° N. Lat., where, by a series of six stations, he obtained the first and a most valuable, transverse section of the East Greenland Polar Current demonstrating the vertical and horizontal distribution of temperature in this current and its underlying waters, as also in the sea east of the current [RYDER, 1895, pp. 191—279]. RYDER's temperatures were taken with Negretti & Zambra Reversing Thermometers, and appear to be trustworthy; they are the best deep-sea temperatures taken in the Norwegian Sea up to that time. The determinations of the specific gravity and salinity of the sea-water, are not sufficiently accurate [cf. NANSEN, 1902, p. 407; 1906, pp. 58—59]. One of RYDER's most important oceanographic results is perhaps his discovery of a layer of warm water underlying the cold water of the Polar Current near the Greenland coast.

During the *Fram* Expedition across the North Polar Basin, in 1893—1896, no oceanographic observations of importance were made in the Norwegian Sea; but its investigations of the physical conditions of the North Polar Basin are nevertheless important for an understanding of those of the above-mentioned sea, especially the East Greenland Polar Current, the underlying warmer waters, and the bottom-water, etc. The observations of the deep-sea temperatures are fairly accurate, especially those taken in the various summers; but the determinations of the specific gravity and salinity are not satisfactory, as they were chiefly made by means of floating hydrometers [NANSEN, 1902; 1904].

In 1893—94 Mr. H. N. DICKSON [1894], on board the *Jackal*, made several sections, with observation-stations, across the Færoe-Shetland Channel, and investigated the oceanographic conditions of this very important region.

In the autumn of 1893 Dr. JOHAN HJORT began oceanographic investigations along the southern and western coasts of Norway on board the *Heimdal* of the Royal Norwegian Navy. These investigations have been carried on during succeeding years especially in the regions of the spring herring fisheries. In January, 1895, Dr. HJORT also made similar investigations on the Vikten Banks off the Namdal coast; and a number of vertical series of temperatures and water-samples were taken by Captain KNAP in the Lofoten waters, in February and March, 1895 [HJORT, 1896]. Simultaneously with these coast investigations, surface-temperatures and water-samples were also, by Dr. HJORT's arrangement, regularly collected, after 1894, along various Norwegian steamship routes between Norway, England, Hamburg and Antwerp. The whole material thus collected was described and discussed by Dr. HJORT in 1895 [1896] and much valuable information has been obtained, especially with regard to the coast-waters along the coasts of southern Norway, their vertical and horizontal distribution, and their seasonal and annual variations. The deep-sea temperatures were chiefly taken with the NEGRETTI & ZAMBRA Reversing Thermometer, and are on the whole trustworthy. The determinations of the salinities, however, like all salinity-determinations of that time, are not sufficiently accurate as regards oceanic waters; but as far as the coast-waters, with their great variations, are concerned, they are nevertheless of some value.

In the succeeding years, 1895—1897, Dr. HJORT, partly in coöperation with Mr. O. NORDGAARD and Dr. H. H. GRAN, continued his investigations and extended them northwards as far as the sea off Lofoten. He was also able to extend them across the Norwegian Sea by means of a great many vertical series of observations taken down to 200 and 300 metres during two cruises of the *Heimdal* of the Royal Norwegian Navy, between Norway and Iceland, in May 1896 and 1897, and in the *Antarctic* and another vessel (both belonging to Mr. J. BULL of Tönsberg) between Utsire (Norway) and Iceland in March, 1897, and between Iceland and Hammerfest in April, 1897. By HJORT's arrangement, numerous surface-observations were also collected by several captains of Norwegian sealing-vessels in the Norwegian Sea between Norway and the Arctic regions (near Jan Mayen and Spitsbergen) in 1896 and 1897. The material thus obtained has been described and discussed by HJORT and GRAN [1899]. The great annual variations which they believed they had found in the extent and width of the warm Atlantic Current in the Norwegian Sea, are based upon the values of salinity obtained by titrations of the water-samples collected. The determinations of the salinities are, however, not sufficiently accurate to prove anything in this respect, the upper and lower limits of the errors of observation being obviously farther apart than the possible amplitude of the variations of salinity in the Sea.

The oceanographic investigations by Mr. MARTIN KNUDSEN [1898] of the Danish *Ingolf* Expedition (under the command of Admiral C. F. WANDEL), in 1895—1896, in the sea round Iceland and Greenland, and between eastern Iceland and Jan Mayen mark an important advance in the knowledge of the eastern part of the Norwegian Sea Basin. The deep-sea temperatures were determined by reversing thermometers from NEGRETTI & ZAMBRA, and also by some of M. KNUDSEN's construction. The thermometers were carefully tested and controlled, and the temperatures obtained appear to be very trustworthy. KNUDSEN's determinations of the salinity of the water-strata are much better than those of previous expeditions, but his values, especially for Atlantic water and bottom-water, are nevertheless not sufficiently accurate [cf. NANSEN, 1906, p. 57] to be of much value for comparison with modern observations. MARTIN KNUDSEN's investigations yielded valuable information respecting the East Iceland Arctic Current, the warm Atlantic Current on the south coast of Iceland, and the Irminger Current, the last-named dividing into two branches one turning west and south-west in Denmark Strait towards the East Greenland Polar Current, and one running towards the north-east and east round the north coast of Iceland. The courses of these currents were traced through numerous stations. KNUDSEN's observations confirmed MOHN's view that no cold bottom-water from the Norwegian Sea runs over the Færoe-Iceland Ridge. His observations in Denmark Strait also indicate that no appreciable quantity of water of this kind crosses the Iceland-Greenland Ridge, although at one station (Stat. 12, see *l. c.* Section *X*, Pl. XXIV), there was perhaps a slight indication of it at a depth of 1958 metres.

During the Ingolf Expedition the bathymetrical features were also studied by numerous soundings taken in the above-mentioned regions of the sea [C. F. WANDEL, 1898].

During ANDRÉE's expeditions to Spitsbergen in 1896 and 1897, numerous observations of the surface-temperature and salinity of the sea between Norway and Spitsbergen were collected at the request of Prof. O. PETTERSSON and Mr. G. EKMAN(1). Prof. SVANTE ARRHENIUS who accompanied the expedition of 1896, in the *Virgo*, took also a number of vertical series of temperature and water-samples. Six of these series are of special interest, ARRHENIUS's Stations I—VI lying in a line, extending in a south-westerly direction from the north-western corner of Spitsbergen, and crossing the Spitsbergen Atlantic Current. Both the temperatures and the water-samples were taken by means of a Pettersson Insulated Water-bottle of the old construction. They are not sufficiently accurate [cf. NANSEN, 1906, pp. 59—60]; but this Section is nevertheless valuable as it gives information concerning the warm current west of Spitsbergen.

In the years 1896—1900, two sealers of Tromsö, capt. H. ANDRESEN and capt. H. C. JOHANNESEN, took observations of surface-temperatures and samples of surface-water, for the Bergen Museum, during their cruises between northern Norway and the sea between Jan

(1) O. PETTERSSON, G. EKMAN, and P. T. CLEVE [1898].

Mayen and Spitsbergen. These observations have been described by Mr. O. NORDGAARD [1901].

In 1898, between March and September, numerous surface-observations and some vertical series were taken, by Dr. HJORT's arrangement, in the Norwegian Sea, between Norway, Iceland, and the Arctic regions, by the Heimdal, of the Royal Norwegian Navy, and several Norwegian sealers and other vessels. This material, and also a few series of surface-observations from 1897, have been described and discussed by Dr. H. H. GRAN [1900] who during the summer, July—September of 1898, as well as the following summer, 1899, made oceanographic investigations in the region of the West-Fjord and the Lofoten and Vesteraalen Islands, where he took numerous vertical series of temperature and salinity.

During the NATHORST Arctic expedition in 1898, most valuable soundings were taken in the Greenland Sea, west of Spitsbergen, by which it was proved that the so-called "Swedish Deep" does not exist. In the region of the supposed great depth of 4846 metres (2650 fathoms) of the *Sofia* (1868), there was only found a depth of 2690 metres, and somewhat farther south 2750 metres. The greatest depth observed in the sea west of Spitsbergen was 3160 metres [cf. NATHORST, 1900, I, pp. 193—197; HAMBERG, 1906, pp. 40—42.]

Observations of Physical Oceanography during this expedition were taken by Dr. AXEL HAMBERG [1906]. The deep-sea temperatures were chiefly taken by reversing thermometers of NEGRETTI & ZAMBRA and of M. KNUDSEN, and the observations appear on the whole to be very trustworthy (1), although HAMBERG himself states that they could not be made very accurately owing to the shortness of time. The deep-sea water-samples were chiefly taken with two water-bottles of HAMBERG's construction, and with an old EKMAN Water-Bottle (of the old con-

(1) One exception to this is the temperature of 0·6 ° C. at 1000 metres, Station *M*, in 77 ° 39′ N. Lat. and 1 ° 18′ E. Long. [1906, p. 37, & Pl. III]. Such a high temperature cannot occur at this depth in this region; and moreover the observations themselves prove the impossibility of it, as the values of temperature and salinity (34·94 ‰) give a much lower density (28·04) at 1000 metres than at 500 metres, where it is 28·10. Provided that the temperature of — 0·05 ° C., at 500 metres, has been correct, the temperature at 1000 metres has probably been about — 0·7 ° [cf. NANSEN, 1906, Pl. X].

struction). Hamberg [1906 p. 13] says about the latter instrument that it leaked, sometimes even appreciably, and his values of salinity seem to indicate that the two other water-bottles have occasionally done the same, which is hardly to be wondered at, seeing that the lid and bottom of the bottles were united by a stiff rod or tube, as in the Sigsbee and in the old Ekman water-bottles, and only dropped by their own weight to close the water-bottle, without anything to press them together. A Pettersson Insulated Water-Bottle was also sometimes used for moderate depths. The amount of chlorine in the water-samples was determined by titration and the salinities computed according to the method formerly used by O. Pettersson. Dr. Hamberg has however not been aware that the values of salinity obtained by this method are not directly comparable with those of Knudsen's Tables, but should be about 0·05 ‰ higher or more [cf. Nansen, 1906, p. 60]. His values of density (and specific gravity) computed by Knudsen's Tables are therefore too high. His values of salinity do not appear to be quite trustworthy, as is proved by his salinities of the "bottom-water" from depths between 1000 metres and the bottom, and with temperatures below 0° C. His values [1906, pp. 37 & 38] vary between 34·94 and 35·08 ‰, while they should have been, about 34·97 ‰, with his method (or from 34·92 to 34·93 ‰ according to Knudsen's Tables). It is impossible to say whether this inaccuracy has been chiefly due to faults in the water-bottles, or to evaporation through the cork-stoppers of the bottles in which the samples were brought home, or to errors of the titrations.

Hamberg has taken a number of most interesting stations with deep-sea observations between Norway and Spitsbergen and in the Greenland Sea, which will be mentioned later. His series of five or six stations, in about 78° N. Lat., between Spitsbergen and the ice are of special interest to us. Our Pl. XIII of the present memoir, had been printed before Hamberg's work appeared, so that his results could not be introduced in them.

Hamberg also collected numerous surface-observations during the expedition. In June, July, and August of the same year, surface-observations (temperatures and water-samples) were collected from the Spitsbergen waters and the Greenland Sea by three Norwegian sealers from Tromsö, Capt. S. KRÆMER, Capt. J. KJELDSEN, and Capt. K. JOHANNESEN. By means of this great observation-material, HAMBERG has been enabled to give an important description of the distribution of the temperature and salinity on the sea-surface in these regions in July and August 1898 [1906, Pl. II]. His description of an isolated area of water with comparatively high salinity (above 34·0 ‰) along the northern coast of Spitsbergen, is of special interest as also that of a branch of similar waters extending westwards into the Greenland Polar Current in 78° N. Lat. The latter branch indicates, according to our view, that a part of the Spitsbergen Atlantic Current is deflected westwards between 78° and 79° N. Lat. which is also proved by HAMBERG's most westerly Stations *N* and *O*.

By numerous drift-bottles, thrown out during the expedition, HAMBERG has also studied the direction of the surface-currents.

During the NATHORST Expedition to East Greenland in 1899, surface-observations and a number of vertical series of temperatures and salinities were taken by Dr. FILIP ÅKERBLOM [1904]. The series taken in the region of the Polar Current off the east coast of northern Greenland, are of special interest (cf. our Pl. XIII, Stats. N VI—NXII, in map of Stations). ÅKERBLOM's values of the deep-sea temperatures observed may be assumed to be on the whole fairly satisfactory; but his salinities are less trustworthy [cf. NANSEN, 1906, pp. 60 & 61]. His observations give additional information about the nature of RYDER's intermediate layer of warm water underlying the cold water of the Polar Current.

In May—June and July—August, 1899, Admiral S. MAKAROFF [1901] made two cruises in the *Yermak* to Spitsbergen, and took numerous soundings and vertical series of temperatures in the Norwegian Sea between Tromsö and Spitsbergen, and in a line between England and Spitsbergen, as also in the sea west and north of the latter. MAKAROFF's deep-sea temperatures were taken with reversing thermometers, and appear to be trustworthy, but his numerous specific gravities (and salinities) were unfortunately determined by means of the floating hydrometer, and are of but little value, except for those surface-layers in which the variations are great.

In 1899 O. PETTERSSON gave a preliminary report of surface-observations along two steamship-routes across the Norwegian Sea in March, 1898, which, he considered, proved that the North Atlantic Current was entirely overflowed by colder and less saline Polar water in about 65° N. Lat.

During his expedition to the Greenland east coast, in June and July, 1900, Captain G. AMDRUP took a number of surface-observations (temperatures and water-samples) and three vertical series of temperatures and salinities in the region of the Greenland Polar Current, one west of Jan Mayen and two off the east coast of Greenland [1902, pp. 343—352].(1) AMDRUP's values of salinities, on the whole, are obviously somewhat too high, but after having been reduced by 0·04 ‰ the salinities of his stations II and III agree well with what might be expected [NANSEN, 1906, pp. 61 & 62]. His temperatures were determined by the Pettersson Insulated Water-Bottle of the old construction, and cannot be expected to be very accurate, but are nevertheless very fair.

During the KOLTHOFF-Expedition in the *Frithjof*, to the north of East Greenland, Mr. HJ. ÖSTERGREN, in July 1900, took two vertical series of temperatures and water-samples, down to 3 100 metres, one north-west of Jan Mayen, and one between Greenland and Spitsbergen [PETTERSSON and ÖSTERGREN, 1901, pp. 325—329].(2) The salinities observed are too high and have to be reduced by about 0·10 ‰ or perhaps a little more; and the temperatures, especially for the deep water-strata, are not very accurate, as they were taken with a Pettersson-Nansen Water-Bottle, without even a fixed thermometer, so that the thermometer had to be inserted when the bottle came up. In several cases the releasing propeller of the water-bottle has not acted properly.(3) The observations at these two stations are nevertheless very interesting, as the stations are situated in parts of the Norwegian Sea in which few or no observations had been taken before. At both places layers of warm water, of considerable thickness, were found underlying the cold top-layers.

(1) Cf. our Pl. XIII, Stations *Ap* II—*Ap* IV.
(2) Cf. our Pl. XIII, Stations F II and F I.
(3) Cf. NANSEN, 1906, pp. 62—64.

In 1899 and 1900, Captain C. RYDER, assisted by the Danish Meteorological Institute, studied the currents, chiefly in the sea between Norway, Scotland, and Iceland, and also in the North Atlantic, by means of drift-bottles. A great number of bottles were thrown out by himself and by captains of other ships. RYDER has described the results thus obtained in an interesting paper [1901], and by combining them with the results of similar experiments made during his own expedition in the *Hekla* in 1891—1892, an during the *Ingolf* Expedition in 1896, he has constructed a chart of the currents in the North Atlantic which is interesting in several respects.

The distribution of the ice in the northern and eastern parts of the Norwegian Sea has been described in several publications which should also be mentioned here. The observations have chiefly been made by *Norwegian sealing vessels.* Captain CARL RYDER, in 1896, gave a description of the distribution of ice in the sea off the east coast of Greenland in the years 1877 to 1892 (RYDER, 1896; RYDER and CORA, 1897], chiefly based upon material which had been collected by Prof. H. MOHN from Norwegian sealers. Since 1895 the Danish Meteorological Office (with Capt. V. GARDE as editor) has regularly collected observations of the ice from various sources, and has published them in an annual series of maps, one for each month between March or April and August or September [*The Nautical Meteorological Annual of the Danish Meteorological Institute,* 1895 and following years].(1)

Regular observations of the temperature, salinity, and plankton of the sea-surface have been taken in late years along the routes of Danish ships sailing to Iceland and Greenland, under the superintendence of Admiral C. F. WANDEL. These have been published in several reports by WANDEL, MARTIN KNUDSEN, and C. OSTENFELD. They are of great interest in as much as they contribute to the knowledge of the conditions of the sea-surface along the southern margin of the Norwegian Sea, the observations having been carried on during nearly all the months of the year.

(1) Amongst other publications on this subject, see CHAVANNE [1875]; PETTERSSON [1900]; BRENNECKE [1904]; MEINARDUS [1906].

Period after 1900.

The oceanographic researches which had been begun by Dr. HJORT in the waters along the Norwegian coast in 1893, and carried on during the succeeding years under his superintendence and to a great extent by himself personally, had gradually been extended into the Norwegian Sea. and had yielded results of so much importance that they logically led to the necessity of building a special vessel, by means of which the numerous important problems of this sea bearing more or less upon the Norwegian fisheries, could be systematically studied.

The ship, the *Michael Sars,* was built, and her first cruise, in the Norwegian Sea, in July--September, 1900, to Iceland, Jan Mayen, and Bear Island, marks the introduction of important improvements in oceanographic research as a whole, including especially more exact methods of taking water-samples, and for determination of specific gravity, salinity,(1) and temperature of the sea. It is therefore chiefly observations taken after July 18, 1900, when the *Michael Sars* started, that are of importance in the present day in a discussion of the vertical and horizontal distribution of salinity and density in the Norwegian Sea; whereas the observations of this kind made before that date are not sufficiently accurate for the purpose. The cruises of the *Michael Sars* during the five years, 1900—1904, will be mentioned in the next chapter.

There are a few expeditions of late years which should be briefly mentioned here, as they have added to the knowledge of the Oceanography of the Norwegian Sea.

During the months April to September, 1901, Captain ROALD AMUNDSEN made his first cruise in the *Gjøa*, in the Barents Sea and the Arctic regions of the Norwegian Sea. His oceanographic observations are of great importance, and are much more trustworthy than those of any previous expedition to the Arctic Seas. His vertical series of temperatures and salinities taken in the sea between Jan Mayen, Greenland and Spitsbergen, are of special value, as they clearly prove

(1) The introduction of standard water for controlling the titrations—according to O. PETTERSSON'S and M. KNUDSEN'S proposal—has greatly increased the accuracy in the determination of the salinity.

the manner in which the bottom-water of the Norwegian Sea is formed. The results of AMUNDSEN's oceanographic observations have been described and discussed by NANSEN [1906], who also furnished him with his instruments, and had them tested, and also had the salinity of the water-samples collected determined by titration.

The International Investigations of the Northern Seas began in August, 1902. Besides the Norwegian researches with the *Michael Sars*, the Scotch cruises, especially across the Færoe-Shetland Channel, and the Danish researches in the sea between the Færoes and Iceland and round the latter, are of great importance for the oceanographic study of the Norwegian Sea.(1)

In 1901, the Russian oceanographic investigations in the Murman and Barents Seas commenced under the leadership of Dr. KNIPOWITSCH, and later under Dr. BREITFUSS. The numerous vertical series of observations taken between Norway and Bear Island are also of interest in the oceanography of the Norwegian Sea [KNIPOWITSCH, 1902, 1906; BREITFUSS, 1903, 1904, 1906].

During the summers of 1900, 1901 and 1902 Dr. R. NORRIS WOLFENDEN made physical observations in the Færoe-Shetland Channel. These have been described by H. N. DICKSON [1903]. The determinations of the salinities of the different water-strata are unfortunately so inaccurate that they are of little value.

During the expedition of the Duke of ORLEANS, in the *Belgica*, with Commander A. DE GERLACHE, as captain of the ship, in the summer of 1905 [1906], to Spitsbergen and the north-east of Greenland, oceanographic observations of very great value were made by Mr. E. KOEFOED, the oceanographer of the expedition. A great number of soundings and stations, with vertical series of temperatures and water-samples, were taken in the northern and western parts of the sea between Spitsbergen and northern Greenland, where previously no observations had been taken. Most valuable information regarding

(1) All the observations collected by the International coöperation are to be found in the *Bulletin des résultats acquis pendant les courses périodiques*, published by the Central Bureau for the Study of the Sea in Copenhagen. Among the papers dealing with the Scottish and Danish material may be mentioned: HELLAND-HANSEN [1905 a, b]; ROBERTSON [1905, 1907]; J. N. NIELSEN [1904, 1905, 1907].

the physical conditions in this interesting part of the sea has thus been acquired. The expedition was equipped with the most modern instruments from the Central Laboratory for the International Study of the Sea, in Christiania, and as KOEFOED has carried out the observations with great care, they are the most accurate determinations hitherto obtained by any expedition from any part of the Ocean. It is a strange fact that this previously almost unknown region of the Norwegian Sea is the one from which we have the most accurate and trustworthy observations, and which is therefore the best known. As HELLAND-HANSEN, in coöperation with KOEFOED [1909], has been working up the oceanographic material of the expedition, we have had the great advantage of being able to make use of them for some of our discussions, before our manuscript was quite finished.

II. The Cruises, 1900—1904.

Most of the material discussed in the present memoir has been collected during the cruises of the Norwegian Fishery-Research vessel, the *Michael Sars*, in the years 1900 to 1904. The first expedition with this vessel was made in the months July to September, 1900, in various parts of the Norwegian Sea. In 1901 and the first half of 1902, the ship was occupied with fishing experiments, the oceanographic investigations being limited to some short cruises and comparatively scattered observations in connection with the other work. In May, 1901, and May, 1902, however, extensive oceanographic investigations were made between Norway and Iceland on board the *Heimdal*, of the Royal Norwegian Navy.

When the International Council for the Study of the Sea commenced its work in the summer of 1902, it was agreed that the Norwegian part of the investigations should be carried out during four seasonal cruises yearly (February, May, August and November), along certain routes across the Norwegian Sea, *viz.* from the neighbourhood of Bergen to a point NE of Iceland, and thence back to Lofoten. These routes have in the main been followed in May, 1903, and 1904, in February, 1903, August, 1903, and November, 1903. The following table shows the cruises made for this purpose during the years 1900—1904.

In the table

S indicates the Southern part of the Norwegian Sea
M — » Middle » » » — »
N — » Northern » » » — »

	1900.			1901.			1902.			1903.			1904.		
January	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
February	—	—	—	S	M	—	—	—	—	S	M	—	—	—	—
March	—	—	—	—	—	N	—	—	—	—	—	—	—	—	—
April	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
May	—	—	—	S	M	—	S	M	—	S	M	—	S	M	—
June	—	—	—	—	—	—	S	—	—	S	M	—	S	M	—
July	S	—	—	—	—	—	S	—	—	—	—	—	—	—	—
August	—	M	N	—	—	—	S	—	—	S	M	—	—	—	—
September	—	—	N	—	—	—	—	—	—	—	—	—	—	—	—
October	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
November	—	—	—	—	—	—	—	—	—	S	M	—	—	—	—
December	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

For further particulars see Pl. II, showing the lines of the sections; see also the List of the Stations, to be found among the Tables.

It will be seen that the greater number of the investigations have been carried out in the spring and summer. By far the most extensively studied season is May; while in October, December, January, and April there were no expeditions at all. The conditions in the sea have been investigated twice in February, and only once in November. The lack of observations in winter is mainly due to the very bad weather at sea, which generally makes it impossible to obtain trustworthy observations, and in any case makes the work very difficult. Moreover, when it is dark and stormy, the determination of one's position will in most instances be very doubtful. This was especially the case during the February cruise in 1903, when, on one occasion, it was impossible to decide whether Jan Mayen was actually visible from the ship (in the ice), or, according to the ships journal, was more than a hundred miles to the north. In November, 1903, when the investigations were being made on board the fishery-steamboat *Ask*, the Færoes were suddenly seen through the dark atmosphere; but according to our dead reckoning the islands at the time were supposed to be some sixty miles to the south. As this November cruise, however, only occupied 10 days with the touch at the Færoes to keep our bearings right, the positions of the stations on this cruise may be considered to be fairly trustworthy, the probable error not exceeding 20 miles at the most. But the value of observations collected under such circumstances, is greatly reduced by the uncertainty regarding locality; and it is of course impossible to draw reliable conclusions as to the real extent of the various masses of water.

In 1900 we supposed that the oceanographic conditions of an extensive sea-area such as the Norwegian Sea were fairly regular, and could therefore be examined with sufficiently accurate results by work at comparatively few observation stations, rather far apart, but scattered over the whole area. Hence we paid special attention to the work at each station, trying to get the best possible series of observations to show the vertical distribution of salinity and temperature at certain selected points, lying as much as a hundred miles or more from each other. It soon appeared, however, that the horizontal distribution of temperature, salinity, and density was subject to many more variations and apparent irregularities than was at first supposed (see Chap. VI). In order to obtain a true picture of the conditions, we were therefore obliged to take more stations, and these closer together. This was done during the subsequent cruises, when the distance between the stations was often reduced to some twenty miles or even less. It proved much better to reduce the total area of investigation in order to have numerous stations over smaller areas.

During the cruises of the *Michael Sars* and the *Heimdal*, surface-observations were made as a rule every hour. A great many surface-observations have also been collected for the Norwegian Board of Fishery and Marine Investigations by captains of Norwegian whalers, sealing-vessels, and trading vessels, who have taken the temperature of the sea-surface, and water-samples for titrimetrical examination at certain intervals. Most of this material has been collected from the western and northern areas of the Norwegian Sea, to some extent tracts from which material could not otherwise have been obtained. This material has proved most valuable.

Since 1902, Danish and Scottish oceanographers have investigated the southern borders of the Norwegian Sea, between the North Sea and Iceland. We have here made use of their observations (1) in connection with our own material, for the discussion of special problems of the Norwegian Sea.

(1) These observations have already been published in various Danish and Scottish publications, to which reference will be made later.

III. Instruments and Methods.

When the one of us, Nansen, started the work in 1900, and at Dr. Hjort's request undertook the management of the physical oceanographic research in the first cruise, July—September, 1900, with the assistance of the other, Helland-Hansen, his hope was that he would be able to equip the ship with such perfect instruments, and to introduce new methods that were so materially improved (especially for determining temperature and salinity or specific gravity), that Physical Oceanography could be made a really exact science. This hope was not fulfilled that first year, as there proved to be more difficulties, especially with regard to the determination of the deep-sea temperature, than had been at first expected. The first cruise—that of 1900—ought therefore to be considered as an experimental one. Acting on the valuable experience then gained we have now, however, been able to improve the instruments and methods so considerably, that they have actually attained what may be considered a satisfactory degree of accuracy.

The accuracy of our observations even during the first cruise was considerably greater than that of any previous series of observations from the Norwegian Sea, or from any other ocean-area, and was sufficient to demonstrate the remarkable regularity of the vertical distribution of temperature and density, especially in the deeper strata of the Ocean. The numerous, often great, irregularities in the vertical series of observations of all earlier expeditions were thus proved to have been due to errors of observation.

1. Necessity of Accuracy in Oceanographic Research.

Our experience shows, moreover, that owing to the regularity in the vertical distribution of salinity, temperature, and consequently density, it is of no use to make oceanographic observations in the Norwegian Sea, unless they be made with a high degree of accuracy. The greater part of this sea is composed of water with salinities that do not differ by more than a few tenths per mille. In its central part the salinities are thus always found, by accurate determinations, to be between 34·85 ‰ and 35·20 ‰, although the various masses of waters are of very different origin. When the differences between the various waters are so slight, the seasonal and annual variations are, of course, still slighter, and cannot be detected except by the most accurate observations. In this respect there is some difference between the open ocean and the smaller, enclosed seas or the waters along the coasts, where the various kinds of water generally differ much more from each other, and where, consequently, the variations in the distribution of each water-layer may be more easily traced without such great accuracy in the determinations.

The accuracy required by the International Council for the Study of the Sea is 0·05 per mille of the salinity. This degree of accuracy could not possibly have been attained some 10 years ago, and even now does not suffice, in most cases, for the finding of the variations in the Norwegian Sea. The value of very exact determinations of salinity may be clearly seen by an example, taken from our Plates. In most sections from the southern part of the Norwegian Sea peculiar uncoloured tongues, with salinities below 34·9 ‰, may be seen between the water-masses with higher salinities. The characteristic shape of these tongues may be seen in our sections as well as in those based upon Danish observations (see, for instance, Pl. XXI A and B). They are due to peculiar bodies of water with characteristic movements, and are of great value in elucidating the dynamics of the sea. They could not have been found unless the determinations of the salinities had been accurate within less than 0·05 ‰. Determinations of such slight differences are thus necessary in so exact a study of the oceanographic features of the sea as is now required; the more general features are now well known. With regard to temperature (and density), the conditions are upon the whole analogous.

Observations that are not made with the very best instruments and methods, are therefore, to say the least, worthless, and may be worse than worthless if any conclusions be based upon them. A few examples will elucidate this important point.

During the *Norwegian North Atlantic Expedition of 1876—1878*, as was mentioned above, great pioneer work was done with regard to the Physical Oceanography of the Norwegian Sea, and a primary idea of the horizontal and vertical distribution of temperature, salinity, and density in this sea-basin was obtained. But this idea was more or less erroneous in several respects. The methods generally used at that time, especially for determining the salinity and specific gravity of sea-water, were imperfect, and the water-bottles used during the expedition, have evidently been defective. Professor MOHN's description, in his valuable memoir on the Norwegian Sea [1887], of the vertical and horizontal distribution of the specific gravity (or salinity), and the density of the sea-water in this basin, could not but prove, therefore, to be highly misleading, as will easily be seen by a comparison of MOHN's sections with ours.

Fig. 3 is a reproduction of one of MOHN's sections, between Jan Mayen and Vesteraalen (Pl. XXXVII, Section XV, of his work). Instead of his values for the specific gravity we have introduced the corresponding salinity values (according to Knudsen's Tables). Fig. 4 is a representation of one of our sections, from August, 1900, from the very same part of the Sea. Whereas the isohalines of the former section run more or less vertically from the surface to the bottom of the sea, those in the latter section have a more or less horizontal course. The shape of the mass of Atlantic water (above 35 ‰, marked by cross-hatching) is thus very different in the two figures; whereas our section shows a remarkable homogeneity in all depths greater than 1000 metres, the salinities being between 34·90 and 34·94 ‰, MOHN's section shows great variations in this bottom-water, his salinities ranging from 34·6 to 35·0 ‰. The altogether erroneous results which these determinations (made by the chemists of the expedition) give regarding the density-conditions in that part of the ocean, have been employed by MOHN for discussion of the currents.

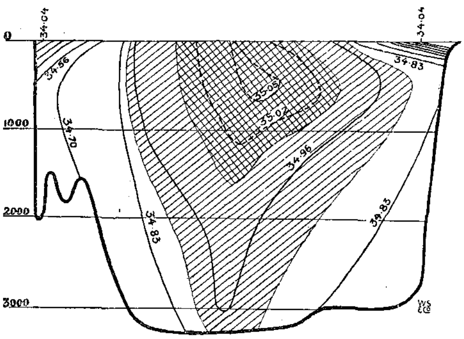

Fig. 3.

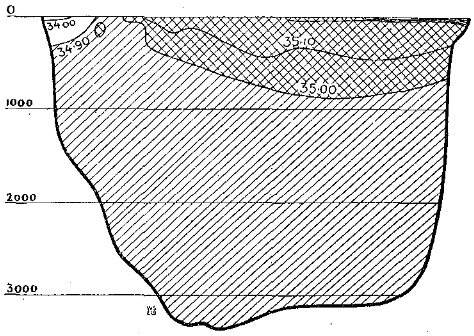

Fig. 4.

Sections Showing The Vertical Distribution of Salinity between Vesteraalen and Jan Mayen, Fig. 3 according to MOHN [1887, Pl. XXXVII], Fig. 4 according to Our Observations *Cross hatching* is salinity above 35·0 ‰; *Single hatching* between 34·9 and 35·0 ‰, and white below 34·9 ‰.

The observations of the great *Challenger Expedition* are also of but little value in this respect. Very important pioneer work was done during that unique expedition, and it is unnecessary to point out here what an important advance it marks in our knowledge of the physics of the Ocean; but nevertheless, very few of the oceanographic observations made during those years will be of lasting value for the future, as they are much too inaccurate. Our recent investigations have proved that the actual variations in the Ocean, especially in its deeper strata, are very much smaller than the errors of the observations, especially of specific gravity and salinity, then made. If, for instance, we look at the determinations made, during the Challenger Expedition, of the specific gravity, salinity, and density of the deep and bottom waters of the North and South Atlantic Oceans, we find most striking differences, often at stations which were quite near to each other. Our investigations of the Norwegian Sea tell us plainly that such differences cannot exist in the open ocean; they must be due to gross errors of observation, whether these be caused by imperfect water-bottles, or by inefficient methods of examining the water-samples taken, or perhaps by both. The observations of the Challenger Expedition, therefore, tell us nothing of what the salinity and density of the bottom-waters of the Atlantic Ocean actually were at the time of the Expedition. To some extent the labour also of more recent expeditions, owing to the imperfect methods employed by them, has been of little use, though their work was otherwise performed with great skill. A recent paper by H. N. DICKSON on the physical Oceanography of the Færoe-Shetland Channel [1903], is an example of this. Mr. DICKSON had observations at his disposal which would have been of the very highest importance if only the methods and instruments employed had been sufficiently accurate. As it is, however, he has in several respects arrived at perfectly absurd results, chiefly because the determinations of the salinity of the sea-water were inaccurate, whether this had been due to imperfect water-bottles, to imperfect methods of preserving the water-samples, or to inaccurate methods of determining their salinity. The errors may even in all probability amount to 0·50 ⁰/₀₀.

The oceanographic observations made by Mr. MARTIN KNUDSEN during the *Danish Ingolf Expedition in 1895 and 1896* [1898], mark a great improvement, especially with regard to the determination of the salinity of the sea-water; but even these observations, which were the most accurate that had up to that time been made, are of little value if required for determining possible changes in the different masses of sea-water. We have, for instance, attempted to compare KNUDSEN's observations east of Iceland, and between Iceland and Jan Mayen, with more recent observations in the same regions, in order to find the possible changes during the intervening years; but we had to give it up, as the determinations of salinity were not sufficiently trustworthy, and showed too great and obvious errors.

If we look nearer home, we find an instance of this in the observations of temperature and salinity (specific gravity) in the *North Polar Basin*, taken during *the Fram Expedition, 1893—1896*. [NANSEN, 1902]. The inaccuracy of these observations is especially fatal, as they are the only ones taken in a region where the difficulty of repeating them is particularly great. They will hardly afford material for future expeditions, equipped with modern and more perfect instruments and methods, to decide whether any changes in the physical conditions of the sea have taken place in that interesting region. Even if we consider the investigations only as pioneer work, they are not satisfactory. In spite of the most painstaking labour to find the probable corrections of the observations, the amount of difference, for instance, in salinity between the bottom-water of the North Polar Basin and that of the Norwegian Sea, cannot be stated with perfect certainty. According to the numerous determinations with the floating hydrometer, during the *Fram* Expedition, the salinity of the bottom-water of the North Polar Basin should be about 35·10 ‰, computed by means of Knudsen's Tables [cf. NANSEN, 1906, p. 100]. If this be correct, as seems probable, this bottom-water must be entirely different from that of the Norwegian Sea, which according to our recent determinations has a salinity of about 34·92 ‰. From this fact important conclusions may be drawn with regard to the shape of the deep basin of the Norwegian Sea and that of the North Polar Basin, these basins being probably separated by a transverse ridge [cf. NANSEN, 1904, 1906; HELLAND-HANSEN and KOEFOED, 1909]. But if the determinations of the salinity, made during the *Fram* Expedition, are on an average about 0·16 ‰ (equal to 0·00012 of specific gravity) too high, there would be no essential difference between the bottom-waters of the two basins, the difference in temperature being no greater than may be easily explained, even if there is some kind of communication between them. The bottom-waters would then have the same origin, being both of them formed in the northern Norwegian Sea (see Chap. XI). In this case the above conclusions drawn from the assumed difference in salinity may be entirely misleading. It will thus be seen to what serious mistakes the use of inaccurate methods in oceanographic research may lead.(1) One or two really accurate and trustworthy determinations of the salinity or the specific gravity of the bottom-water of the North Polar Basin would have been of far more value than the hundreds of observations actually made of this water during the *Fram* Expedition, at the expense of much valuable time.

In order to emphasize the necessity of the very highest degree of accuracy, especially where the deeper strata of the sea are concerned, we will here mention in conclusion an example from the International

(1) See also what Nansen says [1906, pp. 59—63] about the inaccuracy of the determinations of temperature and salinity in PETTERSSON's and EKMAN's paper on ARRHENIUS's oceanographic observations west of Spitsbergen in 1896; in PETTERSON's and ØSTERGREN's paper on the observations taken on board the *Frithjof* in 1900; in AMDRUP's paper on observations in the East Greenland Polar Current in 1900; in ÅKERBLOM's paper on observations taken in the same region during the NATHORST Expedition in 1899, etc.

researches of the sea, now going on. During May 1903 (see Pl. XXI B, Fig. 3) both Danes and Norwegians made investigations in the sea east of Iceland and north of the Færoes. For our vertical and horizontal sections for that month, we have made use of both the Norwegian and the Danish stations. A puzzling fact was then apparent, namely, that at most of the Danish Stations the salinities and consequently also the densities were noticeably higher than at our own, which gave to the isohalines and the isopyknals somewhat startling shapes. On looking at the Danish determinations of the salinity of the typical bottom-water of the Norwegian Sea, we found, however, that they were very often too high. This bottom-water has a salinity of about 34·92 ‰, while the Danish values of salinity for the same water very often varied between 34.98 and 35.06 ‰, which are impossible values. By comparing the values of salinity at Danish Stations situated near two Norwegian Stations with the Norwegian values for the same depths, it was also seen that the former had often a tendency to be considerably higher.(1) But if we had not, in this manner, been able to control the values of the determinations, we should have had no reason to distrust the Danish observations, and might easily have arrived at very startling and perfectly wrong conclusions with regard to the distribution of, and changes in, the different kinds of sea-water.(2)

We have discussed this point at such length in order to urge upon future oceanographers the necessity of a very high degree of accuracy and care, if the investigations are to be of lasting value, and if the important end is to be attained, namely, the collection of really trustworthy observations, which will enable future investigators to trace at least the great features of the variations in the physical

(1) As some of the determinations of the salinity were made on board the Danish vessel soon after the water-samples had been taken, it is not probable that the too high values obtained can be explained by evaporation of the water of the samples through the stoppers of the bottles in which they were kept. The more probable explanation is perhaps that the water-samples have not been left sufficient time to acquire the same high temperature as the Standard Water used for the titrations. The values of salinity obtained will then naturally be too high, and the greater the coldness of the water-samples, the greater will this error be.

(2) J. N. Nielsen has not been aware of the errors of the determinations of salinity, especially in his Section I, and has, therefore, arrived at misleading results [cf. especially 1904, pp. 12 & 22]. See the difference between his Sect. I, Pl. II, and our Fig 3, Pl. XXI B.

conditions of the Ocean. We trust that the examples mentioned above are sufficient to prove that we do not exaggerate this necessity for accuracy.

It is moreover clear that if the physical observations of the deep strata of the Norwegian Sea—say below 600 metres—are not made with the highest possible degree of accuracy, they are of no use; for we could tell with greater certainty what the values ought to have been if we stayed at home, and much time, labour, and money would be saved. The *quality* of the observations, especially in this deep part of the sea, is of much greater importance than their *quantity*.

2. Determination of the Deep-Sea Temperature.

All temperature-readings have been referred to the indications of the *Hydrogen-Thermometer*.

For the determination of deep-sea temperature we adopted two different methods, namely, with the *Insulated Water-Bottle* and with the *Reversing Thermometer*, and these two methods we tried to develope to their highest degree of perfection, hoping thus to be able to determine the temperature *in situ* with at least an accuracy of $\pm$ 0·01° C. We regret to say that the first attempt was to some extent a failure, as a great part of the deep-sea temperatures determined during the first cruise (1900) can hardly claim such a degree of accuracy, the reasons being that our Reversing Thermometers were not sufficiently well made, and that the Insulated Water-Bottle, in which we placed most confidence at that time, is incapable of giving accurate temperature determinations for great depths, owing to the disturbing effect upon the indications of the thermometer produced by the dilatation of the solid parts of the water-bottle (especially the ebonite, the celluloid, and the india-rubber) when being hauled up, this being subsequently proved by experiments.

During the latest cruises of the *Michael Sars,* however, observations of the temperature of the deep strata of the Norwegian Sea have been made at several Stations with the new Richter Reversing Thermometers, and the temperature-determinations thus obtained have an accuracy of $\pm$ 0·01° C.

(a). The Reversing Thermometers.

Reversing Thermometers were used during the cruise of 1900 and in 1903 and 1904. In 1900 we had some long Reversing Thermometers specially constructed by Nansen, and made by NEGRETTI & ZAMBRA, and also some small NEGRETTI & ZAMBRA Reversing Thermometers, of which only one, a very trustworthy thermometer, was used during the cruise. In 1903 and 1904 Reversing Thermometers from C. RICHTER, Berlin, were used.

The chief difficulties with the Reversing Thermometers had hitherto been,

(1) That the mercury did not always break off exactly at the same place in the contraction, and thus no high degree of accuracy was, as a rule, attainable, even if it had been possible to read off the indications sufficiently accurately;

(2) The difficulty of determining the temperature of the broken-off thread of mercury at the moment its indication is read off; and

(3) That the stem of the NEGRETTI & ZAMBRA Reversing Thermometers was very thick, and the graduation of the scale rough and inaccurate. It was therefore difficult to read them off accurately and withouth *errors of parallax.*

We took special precautions in order to avoid these errors.

Specially constructed Reversing Thermometers. For the Fram Expedition 1893—96, Nansen had some NEGRETTI & ZAMBRA Reversing Thermometers specially made for more accurate observations. The distance between the division-marks of each degree was here increased, and the scale divided into 0·1° C.; but the thread of mercury had evidently thus become too thin and light, and would not, as a rule, break off when the instruments were reversed. These thermometers were therefore useless. In order to avoid these difficulties, Nansen designed new instruments with much larger bulbs, so that the degrees (Centigrade) of the scale could be made 1 centimetre long (and be divided into tenths) without reducing the diameter of the thread of mercury. These thermometers were made by NEGRETTI & ZAMBRA, but not as well as might have been desired. In order to reduce the friction between the mercury and the sides of the glass tubes, the bore of the stem was designed to be circular in section instead of elliptical (as on the ordinary reversing thermometers delivered by that firm); but this was unfortunately not done. The thermometers were also ordered to be made of Jena Normal Glass No. 16^{III}; but by some strange mistake only one thermometer *(NZ 18)* was made of this glass. This was by far the best instrument, and gave, on the whole, very satisfactory readings; but it was unfortunately lost by an accident on August 9th, 1900. Another thermometer *(NZ 47)* of the same shape (two other similar instruments were broken before we started) was evidently made of the same glass as NEGRETTI & ZAMBRA's ordinary reversing thermometers. It often refused to register; and during the few weeks of the cruise of July and August, 1900, it became much worse in this respect, becoming at last perfectly useless. In order to reduce the time needed for the broken-off thread of mercury to assume the temperature of the surrounding water, when placed in a water-bath (see later), a quantity of movable mercury, or metallic sand, was enclosed within the glass sheath of the thermometers, and this would run down and surround the end of the stem (containing the broken-off mercury) as soon as the thermometers were reversed.

By comparison with the temperatures taken at the same time with the Insulated Water-Bottle, Nansen came to the conclusion that the two above-mentioned Reversing Thermometers *(NZ 18* and *NZ 47)* had changed the corrections of their zero-points from one day to another, and in his preliminary report [1901, p. 137] he has given a table of these probable changes. Upon a closer investigation of the matter, however, he has since found that this was a mistake, and that the Reversing Thermometers cannot have changed their zero-points much, the apparent variations being probably due to errors of the readings obtained by the Insulated Water-Bottle. These we shall refer to presently. Where simultaneous observations were taken with the two above-mentioned thermometers *(NZ 18* and *NZ 47)*, their corrected readings agree remarkably well.

Small Negretti & Zambra Reversing Thermometers of the old pattern. The best instruments of this type, selected from a stock of 26 thermometers, which had been used for several years, proved to register very well. One of these thermometers was used in 1900; and when read off with a specially constructed Reading-Microscope (see later), it actually gave an accuracy which might have approached the limit of $\pm$ 0·01° C., if it had not been for the rough graduation of the scale.

Water-Bath. In order to determine the temperature of the broken-off thread of mercury when the reading was taken, an arrangement was made in 1900, whereby the thermometers could be easily removed from the reversing apparatus when they came on deck. They were then placed in a water-bath, for 10 or 15 minutes before being read off with a reading-lense or a microscope. The temperature of the water-bath was taken at the same time, and entered in the journal along with the reading. The corrections made necessary by the change in the temperature of the broken-off mercury (from that which it had when reversed), were determined by experiments with each instrument.

The Reading off. The NEGRETTI & ZAMBRA Reversing Thermometers, as already mentioned, have to be read off very carefully in order to avoid serious errors. Special *Reading Lenses* were therefore constructed, by which it was easy to ensure the exact correspondence in level of the eye with the top of the mercury, when the reading was taken. A *Reading Microscope* was also designed by Nansen in 1900. It was made by Mr. LEITZ (of Wetzlar, Germany), and proved a great success. The microscope had a micrometer eye-piece, and a foot by which it could be attached to the thermometer in such a manner that its axis was always perpendicular to the thermometer-stem, and could easily be set level with the top of the mercury. By the aid of the micrometer scale of the microscope, the indications of even the small NEGRETTI & ZAMBRA Reversing Thermometers (divided into whole degrees centigrade) could easily have been read off with an accuracy of $\pm$ 0·01° C., if it had not been for their rough scale.

The Richter Reversing Thermometers. In order to get more perfect thermometers for deep-sea work, Nansen proposed to Mr. C. RICHTER, of Berlin, to try to make some improved reversing thermometers, and pointed out to him the various difficulties he had previously had with instruments of this kind. Richter agreed to make experiments, and the final result was the *Richter Reversing Thermometer*, which in several respects is a great improvement. This thermometer gives the temperatures with an accuracy of about $\pm$ 0·01 ° C. [cf. HELLAND-HANSEN and KOEFOED, 1909].

During the first cruise the *Reversing Apparatus* for the thermometer was released by a propeller which could be set to reverse the thermometer, when hauled up, at any desired point within the first 15 metres of its passage upwards.

The thermometers were generally given 10 or 15 minutes to assume the temperature of the water *in situ.*

During the subsequent cruises releasing propellers were not used, being replaced by arrangements for messengers. The Richter Thermometers were used in 1903 and 1904, especially in connection with the EKMAN Reversing Water-Bottle, which has an arrangement for a messenger (see later).

(b). Determination of Deep-Sea Temperature by Insulated Water-Bottles.

Doubting that the necessary high degree of accuracy could be attained by the Reversing Thermometers at our disposal, Nansen constructed a new model of insulated water-bottle, with concentric water-jackets on the principle first introduced by Prof. OTTO PETTERSSON. In coöperation with Professor PETTERSSON, he also constructed another insulated water-bottle on the same principle. In both instruments (we will call them "the great Nansen Water-Bottle (*N*)") and "the great Pettersson-Nansen Water-Bottle (*PN*)") the principle of insulation was utilized to its full extent, and by the fixing in the water-bottles of the deep-sea thermometers constructed by Nansen for that purpose, the insulation of the enclosed water-sample was essentially improved. With these new instruments we hoped to be able to determine the temperature of the sea-water with the desired accuracy, even at depths of 2000 or 3000 metres; and had this only depended on the insulating properties of the water-bottles, we might have succeeded. But we met with other difficulties which we had not at first sufficiently considered. During the Fram Expedition, 1893—1896, Nansen had already become aware that the dilatation of sea-water, when hauled up from great depths, would have an appreciable effect upon its temperature [cf. NANSEN, 1902, p. 4—6]. In his preliminary report [1901,

p. 136] he also gave a Table of Corrections due to this dilatation(1). At the time, he did not take into account the changes of temperature due to the compression and dilatation of the solid parts of the water-bottle (the metal, ebonite, celluloid, and india-rubber), as he thought that they could not have an appreciable effect upon the temperature of the enclosed water-sample owing to their comparatively small volume. This was a mistake, however.

As soon as the *International Central Laboratory for the Study of the Sea* had been established in Christiania, in 1902, under his leadership, Nansen caused a careful investigation to be made by Dr. V. WALFRID EKMAN of the insulating properties of Insulated Water-Bottles, and also caused the above-mentioned effects due to the compression and dilatation of the solid parts to be examined into. The results of these investigations are given in Dr. EKMAN's excellent paper "On the Use of Insulated Water-Bottles and Reversing Thermometers" [1905]. It will there [p. 15] be seen that the dilatation (caused by relaxation of pressure), especially that of the ebonite and celluloid cylinders, and the india-rubber plates, causes very great changes of temperature. If the bottle be hauled up from 1000 metres, the temperature of the ebonite (according to calculation) will thus fall 0·42° C., of the celluloid 0·63° C., and of the india-rubber 0·99° C. In the Pettersson-Nansen Insulated Water-Bottle, of the smaller size now generally used, the cubic contents of these solid parts amount to about 380 cubic cm., whilst the volume of the enclosed water-sample is about 1650 cubic cm.(2). It is thus evident that the cooling of the solid parts will have an appreciable effect upon the temperature of the enclosed water-sample; and unfortunately the changes in the latter, thus produced, are irregular, and cannot be accurately calculated, as it cannot be ascertained whether the differences of temperature in-

(1) As Nansen had not taken into account in his calculation of this table the changes resulting from pressure, in e (the coefficient of dilatation) and in c (the heat capacity per gramme at constant pressure), his corrections are too small [see EKMAN, 1905, pp. 5—7].

(2) In the great Insulated Water-Bottles used by us in 1900, the volume of the solid parts was smaller in proportion to the much greater volume of the enclosed water, and the conditions of these instruments were consequently more favourable for accuracy.

side the water-bottle have had time to reach equilibrium before the indication of temperature is read off. This fact makes the insulated water-bottles on the whole unsuitable for accurate determinations of the temperature of the deep sea.

The effect of the cooling of the solid parts of the insulated water-bottles is conspicuous in the temperature-readings of our first cruise, in 1900. On several occasions we noticed that during the first few minutes after these bottles had come on deck from depths of 2000 or 3000 metres, the readings of the thermometers had a tendency to sink a trifle, notwithstanding the probability that, at any rate the outer concentric layers of the enclosed water-sample had been somewhat heated by the warmer strata of the sea through which the instrument had been hauled up. At the same time it struck us that after the bottle had been hauled up from great depths (2000 and 3000 metres), almost a longer interval elapsed before the indication of the thermometer began to rise, than when it came from smaller depths. The following examples, on pp. 40 and 41, may be of interest.

According to our view, the explanation of the above facts is, that during the hauling up, the water-bottle is much shaken and moved about, especially so at the moment that it comes up to or above the sea-surface, when it often swings violently to and fro with the rolling of the ship. Owing also to the twisting of the line, or the action of the releasing propeller, it may rotate rapidly while being hauled on board from the water-surface. In this manner the water of the central chamber may have been sufficiently stirred to have acquired throughout a nearly uniform temperature in spite of the heating of the outer water-jackets (when the bottle has been hauled up through warmer water-strata) and the cooling of the solid parts (caused by relaxation of the pressure). It may therefore be expected that from whatever depth the water-bottle be hauled up, or however much the original indication of its thermometer have changed during the hauling up, the temperature-reading will remain unaltered for some time after the instrument has come up. This period may even increase with the depth from which the bottle has been hauled up, because the heating of the water-sample (by the warmer water-strata through which the

Number of Station.	Depth in Metres.	Water-Bottle.	Temperature Reading.	Remarks.
7	910 m.	N	— 1·157 ° C.	Reading remained unaltered for several minutes, and had risen to — 1·14 ° C. after *5 minutes.* The water-bottle was hauled up from 910 m. in 12 minutes.
8	300 »	PN	4·64 »	Readings remained unaltered for *5 minutes* after arrival at the surface.
	400 »	»	2·27 »	
	440 »	»	1·635 »	
9 a	2030 »	»	— 1·515 »	During the first few minutes after the arrival on deck the reading seemed to sink a trifle (to — 1·52 ° C.), after *8 minutes it remained unaltered;* after several minutes more it rose to — 1·50 ° C., and after another few minutes to — 1·485 ° C. Water-bottle was hauled up in about 20 minutes.
34	2800 »	»	— 1·326 »	The water-bottle had struck the bottom, and had been filled with mud. The temperature reading remained *unaltered for 14 minutes*; after *15 minutes* it was — 1·31 ° C. and after *17 minutes* — 1·28 ° C. Hauling up took 19 minutes.
43	3000 »	»	— 1·285 »	*6 minutes* after arrival on deck the reading was — 1·283 ° C. after *9 minutes* it was — 1·27 ° C., and after *11 minutes* — 1·21 ° C. The water-bottle was only given a few minutes for accommodation to the temperature at 3000 m., and was hauled up in 20 minutes.
46	2000 »	»	— 1·135 »	After *5 minutes* the reading was — 1·135 ° C., after *6 minutes* — 1·13 ° C., and after *8 minutes* — 1·11 ° C.
	3000 »	»	— 1·30 »	After *4 minutes* the reading was — 1·306 ° C., after *8 minutes* — 1·31 ° C., after *10 minutes* — 1·29 ° C., after *12 minutes* — 1·27 ° C., and after *14 minutes* — 1·23 ° C.

With the exception of the first observation from 910 m. which was taken with the great Nansen Water-Bottle (N), all the above observations were taken with the same instrument, the great Pettersson-Nansen Water-Bottle (PN), and all readings were taken by the same observer (Nansen). The above remarks on the changes in the readings of the thermometer, may be thus tabulated:

Changes in Temperature Readings from depths of:

	910 m. (Stat. 7).	2000 m. (Stat. 46).	2030 m. (Stat. 9 a).	2800 m. (Stat. 34).	3000 m. (Stat. 43).	3000 m. (Stat. 46).
After						
4 minutes			— 0·005 ° C.			— 0·006 ° C.
5 —	+ 0·017 ° C.	0·00 ° C.				
6 —		+ 0·005 »			+ 0·002 ° C.	
8 —		+ 0·025 »	0·00 »			— 0·01 »
9 —					+ 0·015 »	
10 —			+ 0·015 »			+ 0·01 »
11 —					+ 0·075 »	
12 —			+ 0·03 »			+ 0·03 »
14 —				0·00 ° C.		+ 0·07 »
15 —				+ 0·016 »		
17 —				+ 0·046 »		

It will be seen that, when excepting the case of the temperature-readings from 2800 m. (where the water-bottle had been filled with mud, and the insulation was consequently much improved) and the first reading from 3000 m. (Stat. 43, where the water-bottle had only been given a few minutes at 3000 m. for assuming the temperature), the general rule is that the greater the depth from which the water-bottle is hauled up, the longer will the interval be, after the arrival of the instrument on deck, before the temperature-reading begins to rise: from 910 m. it was about 4 minutes, from 2000 m. about 5 minutes, from 2030 about 8 minutes, and from 3000 m. about 9 minutes. The water-bottle was hauled up by the steam winch with fairly uniform velocity, especially from the greater depths. The insulation of the water-bottle will naturally to a great extent depend upon the differences between the temperature of the enclosed water-sample and that of the water-strata through which the water-bottle is hauled up, as well as that of the air. The temperature of the sea does not change much at depths greater than 1000 or 1500 m.; and as, for instance, the upper water-strata were warmer at Station 7 than at the other stations, we might expect the insulation of the water-bottle to be diminished at this station; but the water-bottle employed there had even a greater power of insulation, and at any rate the differences in this respect are not sufficient to explain the above remarkable facts. At Station 46, for instance, the temperature-reading from 3000 m. remained unaltered nearly twice as long as that taken from 2000 m. at the same station; and the upper water-strata at Station 46 were much warmer than those at Station 9 a (2030 m).

bottle is hauled up, and by the surrounding air) is checked by the cooling of the solid parts of the bottle. The relation between these two disturbing influences cannot be made a subject of accurate calculations, since, for instance, the heating of the enclosed water-sample will greatly depend on the insulating capacity of the water-bottle, on the time spent in hauling the bottle up, and on the temperature of the water-strata through which it has passed. The Insulated Water-Bottle cannot, therefore, give accurate determinations of the temperature of the deep strata of the sea.

Empirically one may, however, get some idea of the magnitude of the temperature-changes when the insulated water-bottle is hauled up from different depths.

In the following table we give the temperature-readings taken simultaneously at various Stations in July and August, 1900, from the same depths with the *insulated water-bottles* and the best *reversing thermometers*.

Explanation of the Table (pp. 44—46).

1st Column, Number of Station and Date of Observation.

2nd Column, the Depth in Metres.

3rd Column, Designation of the Water-bottle. *N* means the great Nansen Insulated Water-Bottle, and *PN* the great Pettersson-Nansen Insulated Water-Bottle.

4th Column, R 69, R 70, and *R 35* are designations of three Nansen Deep-Sea Thermometers used in the Water-bottle, and made by C. RICHTER of Berlin.

5th Column, Temperature-Reading in Centigrade.

6th Column, Temperature-Reading corrected for Instrumental Error. The corrections of the thermometers were as follows:

Corrections of *R 69.*

Scale.	Charlottenburg March, 1900.	August 2, 1900.
° C.	° C.	° C.
0	+ 0·05	+ 0·055
6	+ 0·05	
8	+ 0·05	
10	+ 0·05	
12	+ 0·05	
14	+ 0·06	
16	+ 0·06	

Corrections of *R 70.*

Scale.	Charlottenburg March, 1900.	Christiania June 5, 1900.	July 27, 1900.	August 2, 1900.
° C.	° C.	° C.	° C.	° C.
— 2·4	+ 0·02			
0·0	+ 0·02	+ 0·025	+ 0·065	+ 0·065
2	+ 0·02			
4	+ 0·02			
6	+ 0·01			
8	— 0·04			

Corrections of *R 35*.

Scale.	Charlottenburg March, 1900.	August 2, 1900.	August 13, 1900.
° C.	° C.	° C.	° C.
— 2·4	+ 0·08		
0	+ 0·07	+ 0·05	+ 0·06
2	+ 0·08		
4	+ 0·07		
6	+ 0·07		
8	+ 0·08		

7th Column, The Temperature-Reading after having been corrected for the adiabatic cooling (caused by relaxation of the pressure) of the enclosed water-sample. The corrections have been taken from EKMAN'S calculations [1905, p. 7, fig. 1]. The effect of the cooling of the solid parts of the water-bottle, has consequently not been taken into account.

8th Column, Designation of the Reversing Thermometers (see above, p. 35).

9th Column, Reading of the Reversing Thermometer.

10th Column, Temperature of the Water-Bath in which the Reversing Thermometer was placed for 15 minutes before being read off.

11th Column, Reading of the Reversing Thermometer, corrected for Error caused by the higher Temperature of the Water-Bath. By experiments with the thermometer *NZ47*, it was found that the thread of Mercury, broken off at 0° C., increased its indication 0·0064° C. for each degree its temperature rose. For *NZ18* this increase was 0·0077° C.

12th Column, The Temperature-Reading finally corrected for Instrumental Error.

July 27, 1900 The correction of the Zero-point of *NZ18* = — 0·01° C.
June 6, 1900 » — - » — - *NZ47* = — 0·03° C.
—»— » — at 7° C - » = — 0·038° C.

Owing to the secular contraction of the glass, the minus correction of the Zero-point of the Thermometer *NZ47* increased to about — 0·04° C. during the expedition, as was found by comparisons with *NZ18*.

13th Column, Difference between the Temperatures obtained by Insulated Water-Bottle and by Reversing Thermometer. Provided that there were no other irregularities, this difference would mean the amount of cooling the enclosed water-sample had undergone in the water-bottle owing to the diminution of the pressure of its solid parts when hauled up.

In comparing these two temperature-series, it must be remembered that the releasing propeller of the Insulated Water-Bottle would release the latter and close it, as a rule, nearly 10 metres (or when the sea was very rough, even more) above the strata where the Reversing Thermometers had taken the temperature. Where, therefore, the temperature of the water-strata rises comparatively rapidly upwards, the temperature of the enclosed water-sample would be appreciably higher than that

1	2	3	4	5	6	7	8	9	10	11	12	13
		Temperatures taken with **Water-Bottle**					*Temperatures taken with* **Reversing Thermometer**					
Station & Date 1900	Depth in Metres	Water-Bottle	Thermometer	Reading	Reading corrected for Instrumental Error	*t'* **Temperature** *corr. for adiab. cool.*	Thermometer	Reading	Temperature of Water-Bath	Reading corrected for Error by Water-Bath	*t* *Correct* **Temperature**	Δ $t'-t$
2 $^{18}/_{7}$	10	N	R 69	5·94	5·99	5·99	NZ 47	6·03	?	6·02	5·98	+ 0·01?
	100						»	7·48	11·6	7·453	7·415	+ 0·03
	100	»	R 70	7·415	7·435	7·445	»	7·475	11·7	7·45	7·41	+ 0·035
3 $^{18}/_{7}$	30	»	»	6·87	6·912	6·915	NZ 18	6·995	14·0	6·941	6·93	— 0·015
	50	»	»	7·45	7·477	7·482	NZ 47	7·54	13·65	7·502	7·46	+ 0·022
	70	»	»	7·43	7·457	7·464	»	7·52	13·9	7·48	7·44	+ 0·024
	100	»	»	7·335	7·364	7·375	NZ 18	7·465	13·7	7·417	7·405	— 0·03
4 $^{19}/_{7}$	50	P N	»	6·61	6·657	6·661	»	6·625	11·0	6·591	6·58	+ 0·081
7 $^{23}/_{7}$	400	N	R 35	5·06	5·12	5·15	»					
	450	»	»	3·865	3·93	3·964	»	3·81	12·1	3·746	3·74	+ 0·224
	600	»	»	— 0·48	— 0·415	— 0·393	»	— 0·40	12·1	— 0·496	— 0·505	+ 0·112
	800	»	»	— 1·13	— 1·065	— 1·038	»	— 0·90	12·4	— 1·002	— 1·012	— 0·026
	910	»	»	— 1·157	— 1·092	— 1·06	»	— 0·94	12.05	— 1·04	— 1·05	— 0·01
8 $^{24}/_{7}$	600	»	»	0·33	0·395	0·432	»	0·27	11·7	0·182	0·172	+ 0·26
	800	»	»	— 0·465	— 0·40	— 0·367	»	— 0·25	12·0	— 0·344	— 0·354	— 0·013
	1450	»	»	— 1·01	— 0·945	— 0·885	»	— 0·735	11·4	— 0·828	— 0·838	— 0·047
9 $^{25}/_{7}$	600	»	»				»	— 0·08	8·6	— 0·148	— 0·158	
	800	»	»	— 0·64	— 0·575	— 0·544	»	— 0·46	8·3	— 0·528	— 0·538	— 0·006
	1200	»	»	— 0·98	— 0·915	— 0·867	»	— 0·785	7·8	— 0·851	— 0·861	— 0·006
	1400	»	»	— 1·075	— 1·01	— 0·951	»	— 0·86	7·6	— 0·925	— 0·935	— 0·016

9 a 27/7	1800	»	»	— 1·20	— 1·135	— 1·053	»	— 0·925	10·03	— 1·009	— 1·019	— 0·034
	2100	»	»	— 1·24	— 1·175	— 1·072	»	— 0·96	9·33	— 1·039	— 1·049	— 0·023
10 28/7	160	P N	»			7·18	»					
	200	N	»	4·16	4·225	4·24	»	3·95	9·48	3·908	3·898	+ 0·242
	300	»	»	0·158	0·223	0·235	»	0·195	9·4	0·124	0·114	+ 0·121
	400	»	»	— 0·37	— 0·305	— 0·291	»	— 0·25	9·4	— 0·324	— 0·334	+ 0·043
	500	»	»	— 0·68	— 0·615	— 0·597	»	— 0·51	9·4	— 0·586	— 0·596	— 0·001
	600	»	»	— 0·775	— 0·71	— 0·689	»	— 0·59	9·43	— 0·667	— 0·677	— 0·012
11 30/7	100	»	»	5·83	5·889	5·898	»	6·03(2)	?	6·00	5·99	— 0·092
	150	»	»	5·33(1)	5·391	5·405	»	5·42(2)	?	5·39	5·38	+ 0·025
13 3/8	60	P	R 34	— 1·35	— 1·025	— 1·024						
	80	»	»	— 1 75	— 1·423	— 1.421						
	80	N	R 70	— 1·495	— 1·43	— 1·428	NZ 18	— 1·22	2 9	— 1·252	— 1·262	— 0·166
							NZ 47	— 1·19	2·9	— 1·217	— 1·257	— 0·171
	300	»	»	0·72	0·785	0·798	NZ 18	0 97	4·0	0 947	0·937	— 0·139
							NZ 47	1·00	4·0	0·98	0·94	— 0·142
	400	»	»	0·65	0·715	0·732	NZ 18	0·905	3·4	0·886	0·876	— 0·144
							NZ 47	0·94	3·4	0·924	0·884	— 0·152
	500	»	»	— 0·08	— 0·015	0·005	NZ 18	0·175	3·0	0·153	0·143	— 0·138
							NZ 47	0·205	3.0	0·186	0·146	— 0·141
	550	»	»	0·01(1)	0·075	[0·097]	NZ 18	0·175	3·3	0·15	0·14	?
							NZ 47	0·195	3·3	0·173	0‘133	?
18 6/8	1000	P N	»	— 0·925	— 0·86	— 0·823	NZ 18	— 0·665	5·5	— 0·713	— 0·723	— 0·10
	1300	»	»	— 1·06	— 0·995	— 0 942	»	— 0·805	4·8	— 0·849	— 0·859	— 0·083
	1500	»	»	— 1·135	— 1·07	— 1·004	»	— 0·89	5·3	— 0·938	— 0·948	— 0·056
19 7/8	400	P	R 35	— 0·14	— 0·08	— 0 064	»					
	600	N	R 70	— 0·57	— 0·505	— 0·483		— 0·40	4·8	— 0·441	— 0·451	— 0·03

1	2	3	4	5	6	7	8	9	10	11	12	13
		Temperatures taken with **Water-Bottle**					*Temperatures taken with* **Reversing Thermometer**					
Station & Date 1900	Depth in Metres	Water-Bottle	Thermometer	Reading	Reading corrected for Instrumental Error	*t'* **Temperature** *corr. for adiab. cool.*	Thermometer	Reading	Temperature of Water-Bath	Reading corrected for error by Water-Bath	*t* *Correct* **Temperature**	Δ *t'—t*
29 9/8	600	N	R 70	— 0·28(1)	— 0·215		NZ 18	— 0·26	5·0	— 0·302	— 0·312	
	800	»	»	— 0·635	— 0·57	— 0·539	»	— 0·46	5·1	— 0·503	— 0·513	— 0·026
	1000	»	»	— 0·835	— 0·77	— 0·731	»	— 0·63	5·1	— 0·675	— 0·685	— 0·046
	1000	P N	R 35	— 0·80	— 0·74	— 0·701	NZ 47	— 0·60	4·8	— 0·635	— 0·675	— 0·026
	1300	»	»	— 8·02	— 0·96	— 0·907	»	— 0·765	4·9	— 0·802	— 0·842	— 0·055
	1530	»	»	— 1·115	— 1·055	— 1·988	»	— 0·89	4·8	— 0·927	— 0·967	— 0·021
34 10/8	500	»	»			0·69	»					
	600	»	»	0·355	0·41	0·436	»	0·49	7·4	0.446	0·406	+ 0·03
	2000	»	»	— 1·27	— 1·21	— 1·114	»	— 1·00	8·4	— 1·058	— 1·098	— 0·016
43 11/8	500	»				3·36						
	600	»	»	2·99	3·05	3·09	»	3·16	9·0	3·123	3·083	+ 0·007

(1) Thread of mercury divided; thermometer was taken out and heated in the hand until the mercury reunited and was again inserted; the indication is consequently too high.

(2) The thermometers were given too short time for taking the temperature *in situ*.

indicated by the Reversing Thermometers. This is evidently the reason why, at depths between 600 metres and the surface, the water-bottle has in most cases given higher temperatures than the Reversing Thermometers. Even at greater depths, where the difference of temperature is much smaller, this circumstance will have a tendency to make the temperature-reading taken by the Insulated Water-Bottle somewhat higher than it would otherwise be. It has also to be considered that in the upper water-strata, where the variations in temperature are comparatively great, the movements of the water or the ship, may continually bring the instruments into contact with new water-masses with different temperatures, while the temperature is being taken.

At Stations 2 and 3, in the Geiranger Fjord, the change of temperature with the depth was very slow, but the differences between the temperatures of the water-bottle and those of the reversing thermometers are in this case evidently due to the fact that the errors of the latter had not been determined with sufficient accuracy at those high temperatures, or at any temperatures above zero. The correction of the thermometer *R 70* for temperatures between 6 ° and 8 ° C. was also somewhat difficult, as its error here changed abruptly.

Finally, it may be pointed out that at Stat. 13 (Aug. 3, 1900), and to some extent at Stat. 18 (Aug. 6, 1900), there must have been some irregularity in the errors of the thermometers. As the corrected temperatures taken by the two Reversing Thermometers (*NZ 18* and *NZ 47*) agree well, the differences being between 0·003 and 0·007 ° C. (mean-difference = 0·000 ° C.) it is probable that the thermometer (*R 70*) of the Insulated Water-Bottle has been at fault.(1) It is also a striking fact that at Stations 18, 19, and 29, this same thermometer gave a lower temperature, as compared with that of the reversing thermometer, than before August, 3., 1900; but the irregular error of the thermometer seems to have been gradually decreasing from the first observation on August 3rd (Stat. 13, at 80 metres) until the last observations on August 9th (Stat. 29, 800 and 1000 metres) when the thermometer, as well as the Insulated Water-Bottle and the Reversing Thermometer (*NZ 18*), was lost by an accident. On the latter date the thermometer *R 70* gave — 0·73 ° C. for 1000 metres, while the thermometer *R 35* gave — 0·70 ° C. for the same depth; the error of the former instrument was, therefore, probably 0·03 ° C. greater than assumed on that date, while on the previous dates it must have been still greater. The corrected indications of the two Reversing Thermometers for 1000 metres at Stat. 29 agree within a difference of 0·01 ° C.

By only taking the more trustworthy simultaneous observations into account, where the temperatures of the water-strata changed but

(1) It is however somewhat remarkable that another thermometer (*R 34*), used with PETTERSSON'S small Insulated Water-Bottle *(P)* of the old pattern, gave very nearly the same temperature for 80 metres as *R 70*. For this and other reasons Nansen thought at first [cf. 1901, p. 137, and above p. 35] that the temperatures of the water-bottle were more trustworthy than those of the reversing thermometers; but as both the latter instruments give almost identical temperatures, it would then have to be assumed that they had simultaneously changed their errors by exactly the same amount. This would seem very improbable, especially considering that they were made of different kinds of glass.

little, we have found by a graphic method the probable curve for the increasing change of the temperature-indication of the insulated water-bottle, due to the cooling of its solid parts by relaxation of the pressure, when hauled up from different depths. The following table give the probable corrections of the readings, due solely to this influence.

Table of Corrections for Temperatures taken with the Great Insulated Water-Bottles, due to Cooling of their Solid Parts by Relaxation of Pressure.

Depth.	Correction.	Depth.	Correction.	Depth.	Correction.	Depth.	Correction.
m.	° C.	m.	° C.	m.	° C.	m.	° C.
400	+ 0·003	1000	+ 0·020	1600	+ 0·030	2500	+ 0.037
600	+ 0·009	1200	+ 0·024	1800	+ 0·032	3000	+ 0·039
800	+ 0·015	1400	+ 0·027	2000	+ 0·034		

The reason why the corrections do not increase more with the depth, is obviously that during the hauling up from the greater depths the enclosed water-sample, in the central chamber of the water-bottle, is gradually heated by conduction of heat from the water through which the bottle passes on its way up, and thus the errors, caused by the cooling of the solid parts of the bottle, are diminished. It seems puzzling that the errors (— 0·016° and — 0·023° C.) observed for 2 000 (Stat. 34) and 2 100 (Stat. 9a) metres are actually smaller than those observed for depths between 1 300 and 1 800 metres; but this may be accidental.

(c). *The so-called "Nansen Deep-Sea Thermometers" of the Insulated Water-Bottles.*

As Nansen has mentioned in his preliminary report [1901, p. 132] and also in "Oceanography of the N. P. Basin" [1902, p. 6], he had found it a serious drawback with PETTERSSON's pattern of the insulated water-bottle, that a thermometer (with a different temperature) had to be inserted after the instrument came up, thus causing the enclosed water-sample to be stirred, and the insulation of the concentric water-chambers to be more or less disturbed. He therefore constructed special thermometers for fixing in the lid of the insulated water-bottles, and these were used on our first cruise in 1900. They were a great improvement, for on the one hand they gave much more accurate determinations of the temperature than the old thermometers for insertion, as they insured a more perfect insulation, and on the other hand they saved much time, as they could be read off at once when the water-bottle came up, when once they had had the necessary time *in situ* and during the hauling up to take the temperature.

The thermometers were made by *C. Richter*, in Berlin, of Jena Glass No. 59 III. They are protected against the pressure of water by a strong outer glass tube, with an external diameter of about 13 mm. These glass tubes were evacuated in order to reduce their conductivity of heat. Their lower end was filled with mercury, which surrounded the bulb of the thermometer and made it more sensitive. The thermometers, with the outer tube, were made about 34 cm. long; the distance from the lower end of the bulb to the mark on the scale for $-2°$ C. being about 18 cm.; so that when the water-bottle was closed, the bulb reached about 10 cm. down below the lid into the central water-chamber (cf. Fig. 5). The length of the scale of the thermometer was about 11 cm.; each degree of the scale (Centigrade) was 1 cm. long, and was subdivided into 0·1 °C. By aid of a Thermometer Reading-Lense (excluding the error of parallax) these thermometers could easily be read off with an accuracy of at least 0.01 °C. We have used two sets of these thermometers, one for temperatures ranging from $-3°$ C. to $+8°$ C., and another for temperatures ranging from $+6°$ C. to $+17°$ C.

In order to avoid the change of thermometer when the temperatures varied about 8 °C., Helland-Hansen, in 1901 had some Nansen-Thermometers made, with divisions from $-3°$ to $+10°$ C. In 1902 and following years, he often used thermometers divided for temperatures between $-3°$ and $+13.5°$ C., the length of each degree being then about 0.7 cm. By means of a reading-lense they could easily be read off with sufficient accuracy. These thermometers with the reduced length of the degree Centigrade may be recommended for daily work, for the upper water-strata. According to what has been said above, the insulated water-bottle can hardly ever be used for the determination of the temperature of the deeper water-strata, where a high degree of accuracy is most desirable.

The thermometers were fixed in the lid of the water-bottle by means of a ring of india-rubber compressed by a screw-ring so as to fit perfectly close round the thermometers. The thermometers also fitted tightly into the holes in the india-rubber plates of the lid.

One drawback with the thermometers used during the first cruise, was that the bore of the stem (*i. e.* the space above the mercury) was evacuated. If therefore, by a rise of temperature, the mercury had reached the upper reservoir of the thermometer-stem before the water-bottle was lowered into the water, the thread of mercury would often break off during the contraction, and a part of the mercury remain in the upper reservoir. When the water-bottle was once more brought up on deck, the thermometer had to be taken out, heated in the hand until the mercury re-united, and then again inserted in the bottle; but the accuracy of the determination of the temperature would thus be impaired.

Another drawback was that, owing possibly to evaporation of the mercury in the vacuum, or perhaps simply to a mechanical reparation of the mercury (*e. g.* by shaking), beads of the metal might be formed in the upper reservoir of the stem, these beads being often so small as to be almost invisible unless a lense or microscope were used. Several apparent changes in the zero-corrections of the thermometers might be thus explained, and probably also the disagreement between the temperatures taken with the Insulated Water-Bottle and with the Reversing Thermometer in 1900 at stat. 13 and stat. 18 (see above p. 47). These inconveniences have since been avoided by filling the tube of the thermometer-stem with an inert gas (nitrogen or carbonic acid). Another advantage of this arrangement may be that the enclosed gas will help the mercury to indicate the correct temperature more easily in cases when the mercury has to contract after having previously been exposed to higher temperatures. Otherwise it might make some slight difference if before the observations, the thermometers were exposed to higher or lower temperatures, unless special precautions be taken, *e. g.* by tapping the thermometers before the readings are taken.

The thermometers of the first few years were tested at the *Reichs-Anstalt* in *Charlottenburg*, and later at the Central Laboratory in Christiania. Their zero-point was tested several times during the voyage in

1900, in ice taken for the purpose from Norway, and on August 2nd, 1900, in snow from the mountains of Dyrafjord in Iceland. Since the beginning of 1903, all our deep-sea thermometers have been tested at the *Central Laboratory* in Christiania; and the zero-points have been determined repeatedly both before and after the cruises, at the Hydrographical Laboratory in Bergen. The thermometers have also occasionally been compared with a standard thermometer of 'verre dur' from BAUDIN in Paris. M. GUILLAUME of the *Bureau International de Poids et Mesures* has shown Nansen the great favour of determining the corrections of this instrument.

3. Water-Bottles. (1)

The Great Nansen Insulated Water-Bottle.

Having had much experience with the Pettersson Insulated Water-Bottle, during the Fram Expedition 1893—96, Nansen had come to the conclusion that by improvements on the principle of this instrument, it might be possible to construct an insulated water-bottle which could be used for taking trustworthy temperatures, even at great depths. The result was the socalled Great Nansen Insulated Water-Bottle (made by Mr. ANDERSEN of Christiania). Its chief advantages were: (1) the use of the above-mentioned Nansen Deep-Sea Thermometers, fixed with perfect water-tightness in its lid. (2) An unusually high capacity of insulation (3) absolute water-tightness when closed, as the lid was pressed down by excentric levers, multiplying the force of the lead 6 times. The instrument has been already mentioned in Nansen's preliminary report [1901, p. 131, Pl. 2, Figs. 1—4]. It was insulated by concentric water-jackets, and by a number of evacuated glass-tubes. In the inner part there were seven concentric water-chambers, the outer-most cylinder of these having a diameter of 12·5 cm. Outside this cylinder there was a much larger concentric chamber filled with about 80 evacuated glass tubes arranged in two layers (Fig. 5, B) a thin plate of ebonite being inserted between the layers, in order to

(1) All the water-bottles used during the first cruise, in 1900, were provided with releasing propellers. During the subsequent cruises, messengers have always been used, and not propellers.

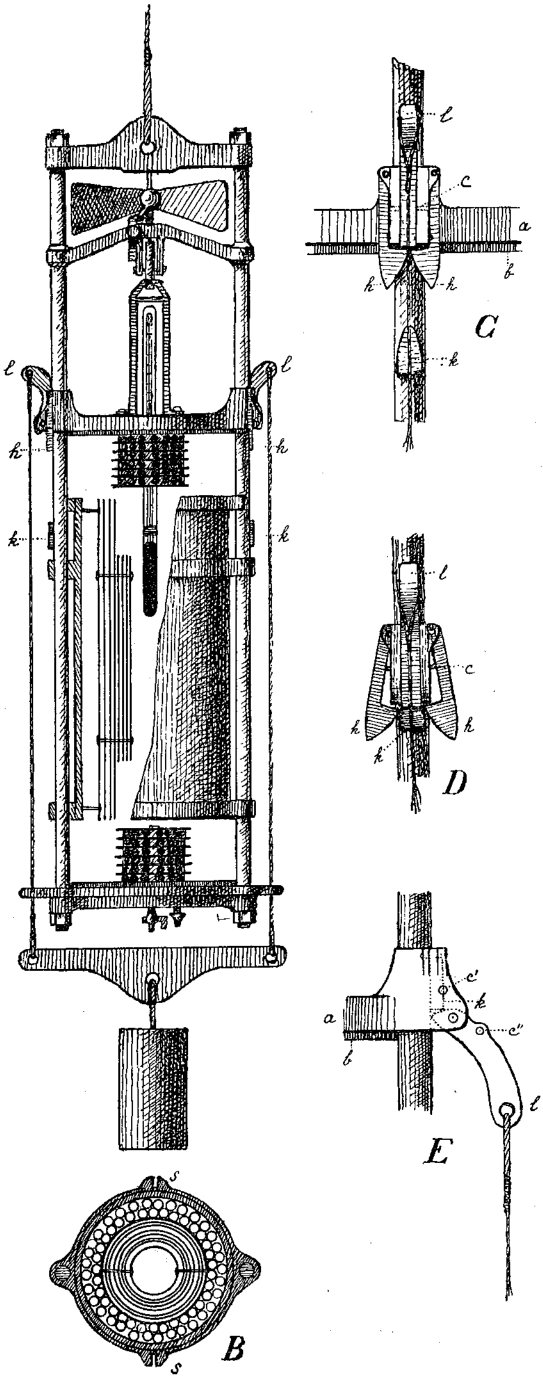

Fig. 5. The Great Nansen Insulated Water-Bottle. Scale of *A* and *B* $^1/_{10}$ of natural size. *C*, *D*, and *E* $^1/_5$ of natural size.

diminish the circulation of the water among the tubes. In the lid and the bottom, there were 7 plates of india-rubber, placed horizontally, alternating with intervals of insulating water-layers. The water-sample in the central chamber of the bottle was thus protected against conduction of heat from its surroundings, at each end by 6 horizontal water-layers and 7 plates of india-rubber (having altogether a thickness of about 7 cm.), and on the sides by 7 thin concentric water-layers, and one thicker concentric water-layer containing evacuated glass tubes, having altogether a thickness of 6 cm. The insulation was consequently very complete.

The arrangement (see Fig. 6) for releasing the lid by a propeller when the instrument was set, was the same as that mentioned in the "Oceanography of the North Polar Basin" (NANSEN, 1902, p. 138). By means of a stopper (Fig. 6, *s*), which could be lengthened or shortened by a screw (*b*), the propeller could be set to release the lid of the water-bottle at any desired distance within the first 15 metres of its passage upwards. The propeller always worked without a hitch; it never failed to release when desired, and the possibility of releasing unintentionally was precluded. When set, the cylinders were suspended under the lid by two long rods, one on each side, sliding in two slots (Fig. 5. B, *s*, *s*) at the upper end of the external brass cylinder. These rods had balls at their lower end, which would catch in the slots and raise the cylinders when the lid was raised.

When the instrument was set the excentric levers *(l, l)* were kept in position by two hooks (Fig. 5, C, *h*, *h*), having each a pin (*c*) that fitted into a hole (E, *c*'') in the lever. When the lid was released and dropped on to the cylinders *in situ*, these two hooks *(h, h)* were pushed aside and opened, in passing the notch *k* (see Fig. 5, D), thus releasing the excentric levers. These, being heavily weighted by the lead attached to them, instantly dropped, and in so doing, their inner, short ends were caught under the said notch (Fig. 5, E, *k*), and pressed the lid down upon the cylinders, and these again upon the bottom, with a force amounting to six times that of the weight of the lead. Thus the water-bottle would be locked with absolute water-tightness, and every possibility of the lid being again lifted, or the slightest chance of water entering during the hauling up, was precluded. This was an important improvement upon most of the earlier water-bottles.

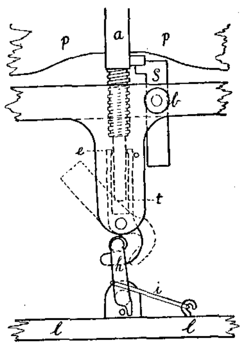

Fig. 6. Releasing Arrangement.

The Deep-Sea Thermometer was fixed so as to be water-tight, by a screw and a ring of india-rubber, to the brass lid, and passed, by means of small round holes which it fitted excactly, through the 7 india-rubber plates of the lid.

By a central stop-cock, the water could be tapped from the central chamber, and by two other stop-cocks from the outer concentric chambers. By opening a screw in the lid, air could be admitted to allow the water to run out through the stop-cocks. The total quantity of water enclosed in the bottle was about 5 or 6 litres.

The Great Pettersson-Nansen Insulated Water-Bottle.

In coöperation with Professor OTTO PETTERSSON, Nansen constructed for the cruise in 1900 another large insulated water-bottle, which was made by *L. M. Ericsson & Comp.*, in Stockholm. Many of the improvements of the instrument just described had also been introduced into this instrument. It was arranged for fixed deep-sea thermometers in a similar manner, and was insulated by a great number of concentric water-jackets, separated partly by brass tubes, and partly by tubes of ebonite and celluloid; but it had no evacuated glass-tubes. The bottle would hold nearly the same quantity of water as the former bottle. Its insulation was very good, but it had no arrangement with excentric levers for pressing the lid down and locking it, and was therefore not so absolutely trustworthy as regards water-tightness as the former instrument. Since then, however, Nansen has also had this improvement introduced in the Pettersson-Nansen Water-Bottles made by L. M. ERICSSON. In 1900 the instrument was released by a propeller of ERICSSON's construction which, however, was so arranged that when the instrument was let down through the water, the propeller would screw itself out of the screwthread and run freely. It then sometimes happened that when the bottle was hauled up, the propeller would not at once catch the screwthread again, and thus the lid of the bottle was not released; the bottle was sometimes hauled up as much as 1000 or 2000 metres before the lid was released, and thus the water-sample obtained might be from a stratum entirely different from that expected. This fault was afterwards remedied, generally by using a messenger instead of a propeller. Dr. V. WALFRID EKMAN [1905, pp. 13—15, Pl. I] has described the smaller type of this improved water-bottle, now generally used, and we will not describe it here. Our water-bottles of 1900, were larger and had many more concentric water-jackets than that small instrument and had therefore a better insulation. From 1900 to 1903, the large water-bottle has always been used for depths greater than 600 metres. The small pattern of the improved Pettersson-Nansen Water-Bottles was used during most of the cruises from 1901 to 1903, for depths down to 600 metres.

The Small Pettersson Insulated Water-Bottle.

In 1900, we had two instruments of this older pattern, described by PETTERSSON [1894]. One of them was altered so that a Nansen Deep-Sea Thermometer could be fixed in the lid. This was an improvement, which greatly increased the accuracy of the temperature-determination and also saved much time; and with this arrangement the bottle insulated sufficiently well to be used down to 300 and 400, or even 500 metres. These water-bottles were originally provided with propellers, which did not work with sufficient certainty. Before the cruises during the winter of 1900—1901 they were therefore altered so as to admit of using a messenger.

The Nansen Stop-Cock Water-Bottles.

In 1900 Nansen also had several water-bottles made for attaching to the sounding line at intermediate depths, when deep soundings were taken. One of these water-bottles was made of two brass tubes about 1 metre long and 2 cm. internal diameter (Fig. 7). These tubes had stop-cocks at both ends similar to those used in the Buchanan Stop-Cock Water-Bottle of the Challenger Expedition. (1) The arms of the four stop-cocks are attached by hinges to a rod, placed between the two tubes in such a manner that the tubes are movable up and down, round the hinges formed by the arms of the stop-cocks. At the upper end of the rod is an arrangement for releasing by a propeller, of the same pattern as that of the Nansen Insulated Water-Bottle (see above Fig. 6). When the tubes were raised, and attached by their upper ends to the two hooks that are set by the releasing propeller, the stop-cocks are open, and when the instrument is let down, the water may run freely through the tubes, being forced into them through the

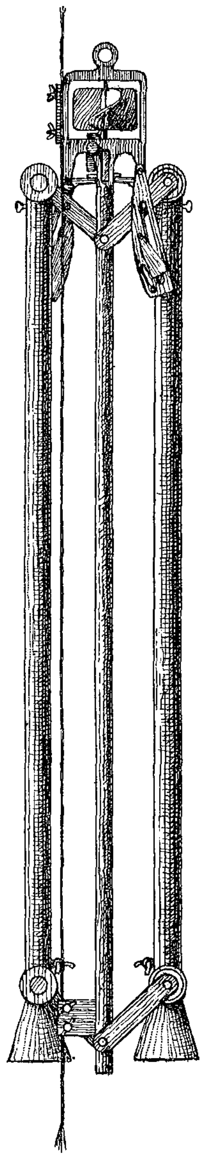

Fig. 7. The Nansen Stop-Cock Water-Bottle. (Scale $^1/_{10}$ of natural size.)

(1) Cf. *Challenger Report,* Narative, vol. I, Part 1, p. 113.

conical mouth-pieces at their lower ends. As the diameter of the apertures of the open stop-cocks, was the same as those of the tubes, the water in the latter, even without these mouth-pieces, would be changed with almost equal rapidity as the instrument passes through the water, it being only impeded by the friction against the sides of the tubes. When the instrument has been hauled upwards a certain distance, which can be regulated as desired, the propeller will release a hook (on the principle mentioned above, see Fig. 6); the tubes become free, and will drop, by their own weight, on the hinges on both sides of the rod, to their lower position, thus closing the stop-cocks. By means of two small ratchets or stop-springs, the tubes are now prevented from again being raised. At the lower end of each tube there is a small stop-cock for taking the water-sample, and at the upper end is a small screw with a hole for letting in air when opened. In this screw there is also a small safety-valve consisting of a tiny hole, over which an india-rubber bladder is tied at the head of the screw, to make it water-tight. When the water expands by being hauled up from great depths, the superfluous water can escape through the tiny hole into this bladder.

By means of jam-nuts at the upper and lover ends of the central rod, the instrument can easily be attached anywhere to the sounding-line.

The instrument worked very well, and closed perfectly; but by some mistake the tubes had not been tinned or nickel-plated inside. The brass was therefore soon corroded by the sea-water, and copper-salts were formed on the inner surface of the tubes. It thus happened that some of the water-samples were so much contaminated by copper-salts that the determinations of their specific gravity showed considerable errors, and the samples were useless for that kind of determination; but the amount of chlorine they contained, as determined by titration, did not appear to have appreciably altered.

Another water-bottle on the same principle was also constructed in 1900. It had only one tube with stop-cocks, the tube on the other side of the central rod being replaced by a reversing apparatus for reversing thermometers. The tube of this water-bottle was widest in the middle, and tapered off towards the stop-cocks at either end; the diameter of the apertures of the tube was thus much smaller than that of the central portion. Though of no great length, this tube would hold more than half a litre of water; and by means of a conical mouth-piece at its lower end, the water was made to flow through it with sufficient rapidity during the descent, without running the risk of water from one water-stratum being dragged down in it into another. We think that this kind of water-bottle is to be recommended for future use, as it is very handy, perfectly water-tight, and can be made at a comparatively small cost.

The Ekman Reversing Water-Bottle.

This water-bottle [cf. EKMAN, 1905, pp. 27—28] was used for greater depths during the cruises of 1903 and 1904. The first instruments made, however, were too delicate; after being used for some time, the brass rods which press the lids towards both ends of the cylinder and close the water-bottle, became bent and therefore did not work sufficiently well. For this reason the instruments had to be frequently tested and repaired. As they are now made, they work very well and are very easily handled.

(4). The Preservation of the Water-Samples.

During the first cruise, in 1900, some titrations of the water-samples were carried out in the laboratory on board, shortly after the samples had been taken. It proved more convenient, however, to store the samples for examination ashore, because the conditions there were more favourable for the attainment of exact results, and also because the time on board was generally fully occupied by other work. All the analyses referred to in the present memoir were thus made some time after the termination of the cruises. The question of the preservation of the samples is therefore an important one, and it must be ascertained whether any appreciable changes have taken place in the water during the time of storing, which sometimes lasted several months.

The glass-bottles used were of two different types, *viz.* small medicine-bottles of ordinary white glass closed with corks, and larger soda-water bottles of green glass with patent-stoppers.

The soda-water bottles contained 450—500 cubic centimetres, and were used principally for the determinations of the specific gravity (by hydrometers of total immersion or by hydrostatic weighings). For such determinations care must be taken that no evaporation takes place, and that the bottles are made of glass containing as little soluable matter as possible. The solubility of the green glass of which the soda-water bottles consisted was tested by Dr. S. P. L. SØRENSEN (Copenhagen), in connexion with his work on the chemical constants of sea-water [KNUDSEN, etc., 1901]. Dr. SØRENSEN has kindly given us the following summary of his investigations on the solubility of different kinds of glass:

March 29th, 1900.

"The examination of the two green bottles, received last month, has been carried out in the following manner: The bottles were filled nearly full with distilled water, were closed with the patent stopper, and then placed for a week on the top of the boiler in the Polytechnic Institute (Copenhagen); the bottles were kept well covered with paper; their temperature varied between 40° and 50° C. After remaining thus during this week, a measured quantity (300—400 cub. cm.) of the water was vaporised to dryness in a previously annealed and weighed porcelain crucible, which was then once more annealed and weighed. The bottles were twice treated with distilled water in this manner.

The experiments were made by *cand. mag.* BJØRN-ANDERSEN, and the result was as follows: As regards the quantity of matter dissolved by this treatment with water, no essential difference was found between the first and the second application; the quantity varied between 0·47 and 0·85 milligramme of dissolved matter in 1 litre of water. If we assume the capacity of the bottle to be 1/2 litre, and its interior surface to measure 350 square centimetres, this means that *for every litre of water used, 0·07—0·12 milligramme of matter has been dissolved per square decimetre of the interior surface of the glass.*

In order to judge of the reliability of these figures, it may be mentioned that the distilled water used contained (before the experiments) in one litre about 0.10 milligramme of non-volatile matter (corresponding to the 0.47—0.85 milligramme mentioned above). The maximum error in weighing on the balance used may be put at ± 0·05 milligramme.

The highest values are certainly too high, as it proved difficult to entirely exclude dust.

For comparison with the values found, the following Table of results that were obtained in the same manner, with other kinds of bottles, are here given:

Kind of Bottle.	Dissolved Matter in each Litre of Water used, per Square-Decimetre of inner Glass-Surface. (After standing one week at 40°—50° C.)
Norwegian, green ½-litre bottles (previously used?) . .	0·07—0·12 milligramme
Danish, common, white, 1-litre bottles (previously unused)	2·45—4·28 »
Danish, green, 1-litre bottles (previously unused)	
1st treatment	0·29—0·44 »
2nd »	0·05—0·05 »
Danish, green 6-litre bottles (previously unused) 3rd	
treatment	0·05—0·15 »
A white, 4-litre porcelain bottle from Professor PETTERSSON, Stockholm (not known whether previously	
used or unused) 1st treatment	0·29—0·29 »
2nd »	0·10—0·20 »

There are no values on record that are directly comparable with these. KOHLRAUSCH states that from the surface of unused Thuringian glass of medium quality, water at 18° C., in the proportion of 1 litre per 10 sq. decimetres of surface (*i. e.* conditions more or less similar to those of the Norwegian bottles), will dissolve, during the first few days, about $\frac{1}{60}$ milligramme per diem, after that less, until in the course of a few months it is only $\frac{1}{150}$ milligramme per diem per sq. decimetre; altogether about 1 milligramme is dissolved per square decimetre in 100 days. If we assume that one tenth is dissolved during the first week, this gives, for every litre of water per square decimetre, an amount of about 0.1 milligramme dissolved by a week's treatment with water at 18° C. The glass, however, is acted upon much more readily by 40°—50° C. than by 18° C. If we also take this fact into consideration we may infer — and anything more than an inference it can never be — that the Thuringian glass of medium quality, mentioned by KOHLRAUSCH, has most resemblance to the above-mentioned Danish white glass, while all the other bottles examined are of a much better quality of glass, and of kinds that are among those least affected by water, concerning which KOHLRAUSCH says that by treatment with distilled water under similar conditions, they give off only about $\frac{1}{16}$ of the above quantity.

S. P. L. SØRENSEN."

It will thus be seen that the solubility of the green Norwegian glass of soda-water bottles in sea-water is very small, practically nothing, indeed, when the bottles have been steeped for some weeks. For our first cruise we were provided with a stock of old bottles of this kind, which had proviously contained soda-water. They were kept, moreover, for a fortnight in hot water, that was heated by steam nearly to boiling point, and changed several times. After the cruise, when the water-samples had been examined, the bottles were not emptied, but they were left as they were until a new sample had to be taken during the following cruise. In this way the bottles were steeped for a very long time, and no appreciable error could possibly arise from dissolving of the glass; in fact, the dissolving of the glass would not affect the fifth decimal place, hardly even the sixth, of the specific gravity of a water-sample kept for months in a bottle such as this, containing 500 cubic centimetres. Even after years have passed, when the examinatiou has been repeated, we have found no appreciable change up to the fifth decimal place.

The patent stoppers used in Norway for soda-water bottles consist of a china lid fitted beneath with an India-rubber ring, which is pressed tightly against the edge of the mouth of the bottle by a lever. The stoppers close perfectly when care is taken that the India-rubber ring is of good quality. We have been furnished with a large nnmber of such rings, which have been kept in water in order to prevent the India-rubber from growing hard and inflexible. (1)

Soda-water bottles have sometimes been used for keeping water-samples for *titration*; but as a rule smaller *medicine bottles* have been used for this purpose. The white glass of these bottles is much more soluable in water than the green glass (cf. above); but this has no influence upon the titrations, as no chlorine will be dissolved. Bottles of this kind have not been used for the determinations of specific gravity.

The medicine bottles used in 1900 contained only 100 cubic centimetres. With this small quantity of water — although large enough for examination — the evaporation through the stoppers may have a great effect; and therefore for the investigations of subsequent years we have used larger bottles of the same type, generally containing 200 or 250 cubic centimetres.

Cork stoppers may easily be the cause of serious errors. If the corks be carefully selected, and driven well down into

(1) Since 1904, bottles of this kind, containing 250—300 cubic centimetres, have been provided by the Central Laboratory for the Study of Sea, Christiania, at a price of kr. 11·00 per hundred.

the bottle (as has always been done in the investigations dealt with here), they may keep the water-samples fairly well for a short time; but they are never perfectly trustworthy, and if the bottles be kept for any length of time — say a month or more — before the samples are examined, considerable changes may occasionally arise from evaporation through the corks. They cannot therefore be recommended for work in which any high degree of accuracy is desirable. As this point is of great importance some details of our experiences may not be altogether superfluous.

In 1900, two medicine-bottles, each containing 100 cubic centimetres, were sometimes filled with water of the same sample. One was examined a few weeks after the samples had been taken, the other was titrated between 11 and 12 months later. Two different standard waters were used, Nos. I and III, respectively (see below). 143 samples were treated in this way, and the following results were obtained:

In 15 cases (rather more than 10 per cent.) the titrations gave exactly the *same* results.

In 32 cases, the first titration gave a *higher* salinity than the second, made a year later. The details will be seen in the following table, in wich ΔS means the difference of salinity, in hundredths per mille, and N the number of analyses:

ΔS	1	2	3	4	5	6	7	8	9	10	11
N	5	12	5	2	3	2	2	0	0	0	1

The differences are evidently mainly due to errors of observation. The constants of the standard waters had perhaps not been determined, with absolute accuracy; the value attributed to standard water No. III being possibly too low as compared with that of No. I. Some of the differences may perhaps also be ascribed to evaporation through the corks of the bottles first examined, during the few weeks that had passed between collection and examination.

In 96 cases the first titration gave a *lower* value than the second, as might be expected as a result of evaporation. The details were as follows:

ΔS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
N	9	11	6	7	5	9	6	6	4	4	4	2	1	4	3

ΔS	16	17	18	19	20	21	22	23	24	25	26
N	2	1	2	1	1	2	0	1	1	0	1

In one instance the difference was 0·36, once 0·40, and once even 0·73 per mille.

Here, too, the small differences may be ascribed to errors of observation; but the cases in which the differences are very appreciable are rather numerous, and evaporation must here have been very great, although the corks appeared to be good

In these 143 cases the mean difference, neglecting the sign, was 0·07 per mille. If the 32 cases in which the first titration gave the higher value are left out of account, we shall obtain a mean difference of 0·08 per mille. This figure may be considered as a rough expression of the mean result of the evaporation during a year under the above conditions. A figure such as this is of little value in itself, *e. g.* for finding a correction, the individual variations being too great; but it nevertheless possesses some interest, in so far as it clearly shows that water-samples kept in this manner will generally be subject to very appreciable changes.

In 1900, 83 bottles which had been examined, were put aside for 5 months, and then examined once more. The corks in some cases were a little damaged by the cork-screw. The mean difference of salinity between the double determinations was 0·08 $^0/_{00}$; and thus the average evaporation in 5 months was fully as great as it had been in the former cases in from 11 to 12 months, thereby showing the effect of an inferior quality of cork.

If corks be used, the examination of the samples must take place as soon as possible. In Nansen's preliminary report [1901, pp. 141—142, Pl. 3] it was pointed out that Helland-Hansen's titrations, made only a week or two after the samples had been taken, showed a distinctly greater regularity and closer accordance with the determinations of the specific gravity, than those made a month after the samples had been taken.

In order to avoid the errors due to evaporation, a piece of parchment-paper was sometimes tied over the cork. This expedient, however, was not sufficiently effective; a layer of paraffin-wax or ordinary wax over the bottle is much better. But if common medicine-bottles have to be used, the best plan certainly is to have stoppers of india-rubber instead of cork. If these are well rammed in and securely tied down, so as to prevent them from getting loose again, they will keep very tight; and as they may be washed, kept in water, and used over and over again, they will not be very expensive in the long run.

5. Determinations of Salinity and Specific Gravity.

Glass bottles of both the types described above were used for most water-samples during the cruise in 1900, and two sets of analyses (titrations and determinations of specific gravity), the one to check the other, were accordingly made. During subsequent years, two similar sets of water-samples have only occasionally been brought home, and then always from depths of 400 metres or more; whilst as a rule the observations are based upon titrations of smaller samples kept in medicine-bottles. The salinities and densities given in the sections for 1901—1904 (Pls. XV—XXIV B) are thus for the most part based on the titrations, the values of salinity and density having been calculated from the amount of chlorine by means of *Knudsen's Tables.* The determination of the specific gravity being the more exact of the two methods, the salinities found in the sections for 1900 (Pls. XIV A & B) are those calculated from the determinations by the Hydrometer of Total Immersion, and not those found by titration. For further particulars the reader is referred to the Tables for that year(1).

The Titrations.

The method of titration used was that of Mohr. The solution of nitrate of silver was kept in 5-litre bottles, standing above the burette. The water from the sample was transferred by the pipette into a tumbler, to which the silver-solution was added, the mixture being constantly stirred meanwhile with a glass spattle. If the salinity is not known, the indicator (K_2CrO_4) was added at once; otherwise it was only added towards the end of the titration. The operation takes from 4 to 5 minutes for each sample. For every 10th to 15th sample of sea-water a titration of standard water was made.

The burettes used were of two types, *viz.* ordinary cylindrical burettes (divided into tenths of a cubic centimetre, and provided with a swimmer) and bulb-burettes. The advantage of the bulb-burette is that the errors arising from the slow drainage along the inner wall of the glass tube, are diminished very considerably. The division of the cylindrical stem below the bulb varied, sometimes giving the approximate amount of total salinity, sometimes that of chlorine. In the first case, the volume of the bulb, from the zero-mark on the capillary tube above it to the upper part of the stem below it, was 32 cubic centimetres; the lower stem of the burette was then, divided into tenths or twentieths of a cubic centimetre from 32 to 36 cub. cm. The silver-solution was so concentrated, that for the titration of water of 35 per mille, for instance, about 35 cubic centimetres was required.

(1) Since the summer of 1902, all the station-observations have been published in "*Bulletin des résultats acquis pendant les courses périodiques*", published by the International Bureau for the Study of the Sea, Copenhagen. These observations will not be given in the form of tables in the present memoir.

For this calculation the chlorine-value corresponding to the reading of the burette (which is then regarded as the approximate salinity) was taken from KNUDSEN's Tables; and a correction, found in those Tables, applied to it in the usual way, and finally the real salinity has been found. — Some bulb-burettes were used, which give a reading corresponding to the amount of chlorine. The cylindrical part of the burette then had divisions marked on it from 17 to 20, either cubic centimetres, subdivided into tenths, or double cubic centimetres, subdivided into twentieths. The volume of the bulb itself in the former case was half that in the latter case; and the concentration of the silver-solution had to be made twice as strong. With the larger bulb-burettes especially (and consequently the more diluted silver-solutions) a reading corresponding to 0·005 per mille is easily attainable.

Knudsen's automatic pipettes have been used for all the titrations, generally those containing about 15 cubic centimetres, and occasionally 20 cubic centimetres. The volume of the water is determined with sufficient accuracy by means of these pipettes [cf. BJERRUM, 1903].

Standard water (No. I) of the same supply as used by KNUDSEN for his determinations of the constants of sea-water was kindly offered to us by him in 1900. It was contained in soldered glass tubes. When the stock came to an end, new standard water was made from a number of water-samples from the Norwegian Sea. These samples were filtered into a large glass balloon, and afterwards carefully kept in old soda-water bottles. The amount of chlorine in this standard water (No. II) was determined by numerous Mohr's titrations, checked by comparison with standard water No. I. Subsequently two other supplies of standard water (Nos. III and IV) had to be made, each of them being determined by comparison with the preceding one, by a number of ordinary Mohr's titrations. In the summer of 1902, standard water was supplied by the Central Laboratory in Christiania. When it was compared with our standard water No. IV the two were found to agree perfectly; the difference between the value of chlorine determined beforehand for this standard water, and the value found from the titrations with the standard water from the Central Laboratory being in fact less than 0·005 per mille. We may therefore conclude that the standard waters used between 1900 and 1902 were determined with sufficient accuracy, and that consequently the observations made during that time are as accurate as the others.

The average accuracy of titrations may be estimated at $\pm$ 0·01 per mille of salinity, or perhaps a little more. At the commencement of our investigations, Helland-Hansen made double titrations of about 260 water-samples in order to test the accuracy of the method. The mean difference of salinity between two determinations of the same sample found by these 520 observations was 0·016 per mille, *i. e.* a mean error of a little less than $\pm$ 0·01 per mille. Such a degree of accuracy can only be obtained by taking great precautions. One of the chief requirements is that the titrations shall be made quite automatically, that is to say, the different phases must be performed in the very same manner and occupy the same length of time. With some practice it is possible to perform the titrations in almost exactly the same length of time, *e. g.* 4½ minutes each. If the examination of the water-samples and of the standard water be thus made in the very same manner, the errors caused by the after-drainage of the silver-solution in the burette will be negligeable; whereas they may otherwise be quite considerable, even though they be reduced by means of the bulb-construction. It is also, of course, very important that the temperature of the water-samples and the standard water is the same; and for this reason all the bottles were always placed together, with the standard water, for some time before examination. When it has been decided to stick to a certain shade of colour as the final one in the process, this same shade can easily by obtained in subsequent titrations, by adding, if necessary, parts of a drop of the silver-solution to the contents of the tumbler, by means of the spattle

The Determinations of the Specific Gravity.

For tracing the very small variations in certain layers, *e. g.* the bottom-water of the Norwegian Sea below 1000 metres, the method of titration is not sufficiently accurate. All such "valuable" water-samples have therefore, as far as possible, been examined by means of the most exact methods, *viz.* by Hydrometers of Total Immersion or by Hydrostatic Weighing.

Nansen's Hydrometers of Total Immersion have been described by Nansen [1900] and Schetelig [1901]. Schetelig has determined the specific gravity of all the larger water-samples, those of 500 cubic centimetres, from 1900, with such hydrometers. The accuracy of the determinations has in most cases been within one unit of the fifth decimal place (*i. e.* within $\pm$ 0·005 of σ_0). By repeating the determinations of the same water-sample, we have as a rule found only very slight differences in the results; but with this kind of observation one has naturally to be careful about the evaporation of the water during the observation.

Hydrostatic Weighing was employed in the case of some samples from the deeper strata, collected in 1903 and 1904. The determinations were made at the Central Laboratory in Christiania, chiefly by Nansen and by Schetelig, and an accuracy of up to a few units in the sixth decimal place of the specific gravity was attained. We shall return to these determinations later, in Chapter XI (The Bottom-Water).

It is worthy of note that in some cases in which the stop-cock water-bottle with two narrow tubes (see above p. 56) had been used, Schetelig, in his first determinations of the specific gravity, obtained values which were obviously several units of the fifth decimal place too high. When these water-samples had been left undisturbed for some days, however, we observed that a bluish sediment had been precipitated on the bottom of the bottles, and upon closer examination this sediment proved to be copper-salts. It was obvious that the inside of the brass tubes of the water-bottle had become corroded by the drying of the sea-water in the air; and the copper-salts thus formed, though nearly insoluble in water, had been carried away by the water-sample. It was therefore quite natural that the first water-sample taken in the day with this water-bottle, would contain most copper-sediment. By leaving these water-samples at rest for several days, and then pouring off the water carefully, without stirring up the sediment on the bottom, the errors caused in this manner were to a great extent eliminated; but nevertheless some of the samples taken with this water-bottle seem to have yielded values that were somewhat too high.

In cases when the water-bottle had struck the bottom, and had been filled with mud, it was also very difficult to obtain trustworthy determinations of the specific gravity of the water-samples, as there was too much mud suspended in the water. In such cases the samples were left undisturbed for a long time, and the water was poured off with great care; but nevertheless this was no actual guarantee that the specific gravity would not be too high. The salinity, however, of these samples could be determined with tolerable accuracy by titration.

It will be well, before going further, to explain our use in these pages of the terms *specific gravity* and *density*. When not otherwise stated, by *specific gravity* is to be understood the specific gravity of the sea-water at 0° C. as compared with distilled water at 4° C., and by *density* the density of sea-water of the actual temperature *in situ* (t° C.) as compared with distilled water at 4° C. Thus the specific gravity depends only upon the salinity, the temperature being always the same (zero); whereas the density *in situ* depends upon both the salinity and the temperature. This is usually expressed in the forms S_4^0 (or S_0) and S_4^t (or S_t) respectively; but it will be more practical to follow KNUDSEN's method of expression, employing $\sigma_0 = (S_0 - 1)\ 1000$ and $\sigma_t = (S_t - 1)\ 1000$ to indicate the respective values of specific gravity and of density. Thus for the sake of brevity we shall speak of "a density of 28·05", meaning "a density *in situ* of 1·02805".

IV. The Basin of the Norwegian Sea.

1. The Area of the Norwegian Sea.

By the name Norwegian Sea we understand the whole sea-area enclosed between Norway, the Shetlands, the Færoes, Iceland, Greenland, Spitsbergen and Bear Island. Its basin is bounded (see Pl. I) towards the east by the Spitsbergen Platform, the continental shelf of the Barents Sea, and the Norwegian Coast; towards the south and south-west by the North Sea Platform, the Wyville Thomson Ridge, the Færoe Platform, the Færoe-Iceland Submarine Ridge; the Iceland Platform, and the Iceland-Greenland Submarine Ridge; towards the west by the east coast of Greenland; and towards the north by a probable submarine ridge between Greenland and Spitsbergen.

The subdivisions of the great Norwegian Sea-area are the *Greenland Sea* between northern Greenland (north of 71° N. Lat.), Jan Mayen, and Spitsbergen, and the *Iceland Sea* between Iceland, Jan Mayen, Greenland (south of 71° N. Lat.) and the Iceland-Greenland Submarine Ridge. A portion of the latter sea, lying between Iceland and Greenland is also called *Denmark Strait.*

The Norwegian Sea lies between the extensive basin of the Atlantic Ocean on the one side, and the deep North Polar Basin on the other. It forms to some extent a thoroughfare for waters travelling between these two seas, and this circumstance has a fundamental effect on its physical conditon and circulation.

Fig. 8. The Norwegian Sea.

Connected with the Norwegian Sea there are also two enclosed shallow sea-areas, in the south the North Sea, with the Skagerak, the Kattegat, and the Baltic, and in the north-east the Barents Sea. The circulation between these shallow seas and the Atlantic is also by way of the Norwegian Sea (with the exception of the comparatively insignificant masses of water passing through the Straits of Dover).

This circumstance has also a considerable influence upon the physical condition of the Norwegian Sea.

Basing our calculations upon our bathymetrical chart of the Norwegian Sea, Pl. I, we have measured, with a planimeter, the area of the entire Norwegian Sea, and the areas enclosed by different isobaths, as drawn in the chart. The final results were as follows:

		Difference
The area of the surface(1) . .	2·58 million sq. km.	
		$0·79 \times 10^6$ km².
The water-area at a depth of 600 m.	1·79 » » »	
		$0·14 \times 10^6$ »
» —»— » » » » 1000 »	1·65 » » »	
		$0·60 \times 10^6$ »
» —»— » » » » 2000 »	1·05 » » »	
		$0·75 \times 10^6$ »
» —»— » » » » 3000 »	0·30 » » »	

The volume of the Norwegian Sea is found by these calculations to be approximately 4·12 million cubic kilometres, and its mean depth about 1600 metres.

The following Table shows the percentage of the area of the bottom of the Norwegian Sea lying at different levels, according to the above measurements. The third column gives the percentage of the sea-bottom below 600 metres lying at different levels between 600 metres and the greatest depths. In this case we consider the continental shelf above the 600 metres' contour as not belonging to the sea-bottom but to the continents.

Level	Percentage of the entire Sea-Bottom		Percentage of Sea-Bottom below the 600 Metres' Contour	
Between 0 and 600 metres	30·6 per cent.			
» 600 » 1000 »	5·4 » »		8 per cent.	
» 1000 » 2000 »	23·3 » »	64·0 %	34 » »	75 %
» 2000 » 3000 »	29·1 » »		41 » »	
Below 3000 »	11·6 » »		17 » »	

(1) As the limits of the sea we have taken the coasts of the above-named lands and islands, the highest part of the ridges separating the Norwegian Sea from the Atlantic Ocean, a line from the Shetlands to Stad, and, in the north, the meridian of 20 ° E. Long. from Norway to Bear Island, a line from Bear Island to Spitsbergen, and from the north-western corner of Spitsbergen along the (supposed) ridge to the north-eastern point of Greenland.

Nearly one third of the whole sea-area covers the continental shelves, and is above the 600 metres' contour, and very nearly two thirds covers the deep sea-basin, while the area of the continental slopes is comparatively very small.

Three fourths of the deep basin area lies between 1000 and 3000 metres' depth.

2. Bathymetrical Features of the Norwegian Sea.

The Bathymetrical Chart, Pl. I.

Our bathymetrical chart, Pl. I, of the Norwegian Sea, is chiefly based upon Nansen's bathymetrical charts of the North Polar Seas, and of the Norwegian Coast, and upon his two charts of the sea round the Færoes and Shetlands, and round Iceland [NANSEN, 1904, Pls. I, XI, XXIII, XXIV].

MOHN's chart of the Norwegian Sea in 1887 [MOHN, 1887, Pl. I] gave the first real representation of the chief bathymetrical features of this basin. It was chiefly based upon the soundings of the Norwegian North Atlantic Expedition, 1876—78, and upon previous soundings mentioned by MOHN [1887, pp. 2—3]. Since that time, important soundings have been taken in the Norwegian Sea chiefly by the various expeditions mentioned in Chapter I, and by the Norwegian, Danish (Icelandic), and British Survey, as also during the cruises of the *Michael Sars*. We have made use of all these soundings for our chart, and have also had the great advantage of being able to introduce into it the soundings taken in 1905 by the Duke of ORLEANS in the sea between Greenland and Spitsbergen. These soundings help to give a more definite idea of the shape and width of the continental shelf of the north-east coast of Greenland, and this again has aided greatly in affording a clearer understanding of the physical conditions of the East Greenland Polar Current.

Just as the last proof of this chart was being revised, we received from Lieutenant ALF TROLLE a map showing the important discoveries of the *Danmark* Expedition, 1906—1908, along the north-east coast of Greenland. We were thus able to have this coastline introduced on the stone before the chart was printed. We consider this a very valuable addition; and the way in which this coast-line accords well with the hypothetical isobaths drawn in the chart, in this region of the sea, is quite remarkable. One fact especially interesting to us is that the projection of the great peninsula north-eastwards, between 81° and 82° N. Lat., seems to strengthen the probability of a submarine ridge running from this part of Greenland to the north-west corner of Spitsbergen.

By some mistake a sounding of 3023 metres, taken at Stat. 35, on June 7th, 1904 (see Pl. XII), was not introduced in our chart, Pl. I. The position of the sounding vas 64° 53′ N. Lat., and 1° 20′ W. Long. The isobath of 3000 metres should consequently have a shape somewhat different from that represented in Pl. I, and the area of the hollow deeper than 3000 metres, will get a wider extension southwards (see Fig. 8), more in accordance with the shape of the 2500 metres' contour. As there is another sounding of 2913 metres in this region, just east of the Greenwich Meridian (see Pl. I) it is probable that the 3000 metres' contour should also approach this place as indicated in Fig. 8. The sounding of 2800 metres to the north-west, may be on an elevation which is a continuation of the elevation extending north-westwards from the mouth of the Norwegian Channel. In Fig. 8 the shape of the isobath of 3000 metres has been altered accordingly.

A small bank with depths of less than 400 metres is indicated in our chart, to the north-east of the Færoes. We doubt the existence of this bank, as it is only based on a single sounding of 373 metres, taken during the Norwegian North Atlantic Expedition in 1876, but not verified by any later soundings. During the cruises of the *Michael Sars* in the summer of 1902, numerous soundings were taken along the edge of the Færoe Platform, between this place of the above-mentioned sounding and the Færoes, which seemed to prove that the sea-bottom formed the regular continental slope from this edge towards the deep basin; but having no soundings from the place specified by Mohn as that of the sounding from 1876, we have thought it right to retain it, and indicate a doubtful bank in this region, until new soundings can be taken, which may perhaps sweep it away. Our uncertainty on this point has somewhat hampered our discussion of the circulation of the sea in this region and in the Færoe-Shetland Channel; for it is obvious that the existence or non-existence of such a bank, extending north-eastwards from the Færoe Platform, will greatly affect the course and direction of the sea-currents in a region which happens to be of particular importance from the fact that various currents meet there. It is therefore most desirable that new soundings should soon be taken in order to determine this point beyond question.

The Chief Features of the Basin of the Norwegian Sea.

Along the eastern side of the Atlantic Ocean, a series of depressions extends in a curved line northwards, following more or less the direction of the east coast of the African and European continents, and extending to the region round the North Pole, where it separates the Eurasian continent from the Greenland-American continental mass. The Norwegian Sea Basin is one of these depressions, having an intermediate position between the Northern Atlantic basins on the one side, and the deep North Polar Basin on the other, and being separated from both by submarine ridges. It is, however, to some extent, a continuation of both the eastern and the western series of depressions in the Atlantic Ocean. These two series of depressions are separated by a ridge on which are situated the islands Tristan da Cunha, Ascension, St. Paul, the Azores, and we may also say Iceland, all of them more or less volcanic. In the same line we also have Jan Mayen, although it is hardly connected with Iceland by any submarine ridge. The western Atlantic depression divides, south of Greenland, into two branches, one running north-west between Greenland and Labrador, and the other north-east towards Denmark Strait. The depression between northern Iceland and Greenland is a continuation of the latter branch, but is separated from it by the Iceland-Greenland Ridge.

In the Norwegian Sea basin there are several deep hollows, separated by low ridges. The most extensive deep hollow is the so-called *Norwegian Deep* [cf. MOHN 1887, p. 6] in the southern part between Norway, Iceland, and Jan Mayen. It has depths of more than 3500 metres (the deepest sounding is 3667 metres). Owing to the scarcity of soundings, it is doubtful whether the ridge, or platform, which we have called the *Helgeland Ridge* (Fig. 8)(1), extending west-northwest from the Helgeland coast, in Norway, may not possibly continue as a low ridge in the direction of Jan Mayen, straight across this Norwegian Deep, dividing it into two smaller hollows. There is great need of more soundings in this region in order to decide this question. The northern hollow of the Norwegian Deep, extending from the Lofoten Islands towards Jan Mayen, we will call with MOHN [1887, p. 6] the *Lofoten Deep*.

A low suboceanic ridge, called by MOHN [1887, p. 5, Pl. I] the *Transverse Ridge*, and rising perhaps 1000 metres or more above the floor of the hollows north and south of it, probably extends from Jan Mayen to the Bear Island Platform, or more correctly perhaps, to the mouth of the great submarine valley of the Barents Sea, the *Bear Island Channel* [cf. NANSEN, 1904, p. 30]. We will call this ridge *Mohn's Transverse Ridge* (Fig. 8). It separates the Norwegian Deep from the hollow to the north, which we will call the *Greenland Deep*. This also descends to depths greater than 3 500 metres. Near the centre of this hollow, a sounding of only 2 195 metres was taken by the Norwegian Expedition in 1878. We take it that this sounding marks a low ridge running out from the north-east, as shown in our chart, Pl. I; but this is naturally quite uncertain.

West of northern Spitsbergen, there is perhaps a small isolated hollow of 3400 metres (*Belgica* Expedition), which may be separated from the greater hollow to the south by a low ridge, a continuation of the ridge probably running westwards off the northern end of Prince Charles Foreland. The so-called *Swedish Deep* [cf. MOHN, 1887, pp. 6 & 7], with depths of 4850 metres, which according to the Swedish soundings of 1868 should have existed exactly in the region of this ridge, has altogether disappeared with the important soundings taken by the NATHORST Expedition in 1898 [HAMBERG, 1906, pp. 40—42], and also by the *Belgica* Expedition under the Duke of ORLEANS.

The sea north and north-west of Jan Mayen, which is probably between 2000 and 2500 metres deep, was called by MOHN the *German Deep*. Owing to the small number of soundings, we really know very

(1) The Plateau on this ridge was called by Nansen [1904, p. 54] the *Vöring Plateau*.

little about the configuration of the sea-bottom in this region; but it seems probable that the deep basin approaches nearer to the Greenland coast there than anywhere else north of Iceland.

In the sea west and south-west of Jan Mayen, the soundings are also far too few to enable us to say much about the configuration of the sea-bottom. We have assumed, however, that a channel with depths greater than 2000 metres may possibly extend south of Jan Mayen, from the German Deep to the Norwegian Deep.

As the configuration of the sea-bottom, even at great depths, has a very great influence upon the directions of currents and the circulation of the sea, even near its surface it is much to be regretted that a more detailed knowledge of the topography of the bottom of the Norwegian Sea has not been acquired, as such knowledge would have been most desirable in discussing the circulation of this sea. It would be reasonable to suppose that many features of this circulation which may now seem puzzling, would then have been easily explained.

The topographical feature which has the most decisive influence upon the circulation and the oceanographic conditions, as a whole, of the Norwegian Sea, is unquestionably the ridge between Scotland and Greenland, via the Færoes and Iceland. The most important part of this again, is the *Wyville Thomson Ridge*, over which by far the greater part of inflowing water has to pass. The mean depth of this ridge between the slope of the Scottish Continental Shelf and that of the Færoe Bank is about 470 and 500 metres, its saddle-depth descending to about 576 metres, judging from the known soundings [cf. NANSEN, 1904, p. 75, Pl. XXI, Section *H*, Pl. XXII, Sect. 45].

North-east of this ridge is the long and narrow *Færoe-Shetland Channel*, forming so to speak, the entrance gate to the Norwegian Sea, as nearly all inflowing Atlantic water has to pass through it. Its nearly level floor is at a depth of about 1100 metres [cf. NANSEN, 1904, p. 74, Pl. XXI, Sect. *H*, Pl. XXII, Sect. 44, Pl. XXIII], and it has comparatively steep side slopes. It widens out to the north-east towards the Norwegian Sea, and from its mouth there seems to be a very gentle slope towards the floor of the Norwegian Deep. Towards the south it communicates with the Atlantic across the Wyville Thomson

Ridge, and towards the west its innermost cirque communicates with the Atlantic, west of the Færoes, through a shallow channel, about 300 metres deep, between the Færoe Bank and the Færoe Platform.

The *Færoe-Iceland Ridge* forms a fairly level plateau at depths of between 400 and 500 metres, with a saddle-depth of about 505 or 512 metres near the Færoes, while some parts of it rise above the 400 metres' contour(1) to 324, 386, and 330 metres below the sea-surface [NANSEN, 1904, pp. 83 & 84, Pl. XXII, Sect. 46, Pl. XXIV].(2)

The Iceland-Greenland Ridge has a saddle-depth of perhaps about 600 metres near Iceland, while the greater part of the ridge probably rises much higher, to within 400 and 300 metres of the sea-surface. Towards the Greenland side there seems to be a broad platform with even smaller depths, between 260 and 350 metres [NANSEN, 1904, p. 84, Pl. XXIV]; but the soundings are unfortunately far too few in this important region, through which nearly all water running out of the Norwegian Sea into the Atlantic, has to pass.

North-east of the Iceland-Greenland Ridge there is a deep narrow channel, which we will call the *Iceland-Greenland Channel.* It is very similar to the Færoe-Shetland Channel, although perhaps somewhat wider and its floor perhaps at a somewhat deeper level, namely, about 1400 and 1500 metres. Just as most of the inflowing Atlantic water has to run into the Norwegian Sea along the eastern side-slope of the Færoe-Shetland Channel, and over the continental shelf to the east of it, so most of the outflow of water has to run out along the western side slope of the Iceland-Greenland Channel and over the Greenland continental shelf to the west of it.

The Spitsbergen Greenland Suboceanic Ridge is little known. Only some few soundings have been taken on it near the Spitsbergen side, showing depths of 560, 700, and 786 metres, and there are no soundings from its Greenland side. The probability is that its saddle-depth is

(1) In Plate I there is an error in the colour on this ridges. The two closed curves inside the 500 metres' contour, are 400 metres' contours, and the areas enclosed by them should have been of the lightest blue shade, marking them as being less than 400 metres deep.

(2) Since these Plates were drawn, several new soundings have been taken by the Danish Oceanographic Survey on this ridge. These soundings on the whole, confirm the conclusions drawn from the earlier soundings.

between 700 and 800 metres, judging from the physical conditions of the water-strata under the Polar current, east of northern Greenland, as compared with those of the North Polar Basin. It seems also probable that the ridge rises much higher on the Greenland side, and the depths below sea-level may there be between 200 and 400 metres.

The angles of the *side-slopes* of the Norwegian Sea Basin vary much at different places. As a rule, the angle of the slope is a few degrees, but may in exceptional cases amount to even 20°. The angles seem to be steepest off the Lofoten and Vesteraalen Islands, off the west coast of Spitsbergen, and off the east coast of Greenland in about 73° and 75° N. Lat. Off the north-east coast of Iceland, the north coast of the Færoes, in the southern part of the Færoe-Shetland Channel, and off Storeggen in Norway, there are probably also fairly steep descents. At other places the side-slopes are very gentle, *e. g.* off the mouths of the Norwegian Channel (off Stad in Norway), off the coast of Helgeland, off the mouth of the great submarine valley of the Barents Sea, off the north coast of Iceland, and the northern slope of the Færoe-Iceland Ridge.

If we start from the Færoe-Shetland Channel, and follow the side-slope round the whole of the Norwegian Sea Basin, we shall meet with the following very prominent features, which may affect the course of the currents. After having passed a projecting elevation (probably a waste-fan) in front of the mouth of the Norwegian Channel, we come to what is probably an embayment in the slope off the Romsdal coast: but there are no soundings in this region, so that we know very little about the embayment. Farther north we find a greatly projecting elevation or plateau (the Helgeland Ridge with the Vöring Plateau) extending north-westwards from the continental shelf off the Helgeland coast. This plateau or ridge probably has a tendency to give the current, running along the continental slope, a westerly direction. Having passed this plateau, we come into the Lofoten Deep along the very steep slope off Lofoten and Vesteraalen. From this coast the continental slope of the continental shelf extends more or less regularly northwards to Spitsbergen, having probably a low elevation (or waste-fan) spreading out in a westerly direction in front of the mouth of the Bear Island Channel. This channel and the banks to the south form irregularities in the surface-relief of the continental shelf, which must naturally influence the surface-currents, turning off eastwards into the Barents Sea. Off the northern west coast of Spitsbergen the soundings also seem to indicate several irregularities and projecting ridges, which evidently have a great effect upon the course of the currents, even at the surface.

Off the northern east coast of Greenland, the continental shelf seems to be very broad, and its surface to be much cut-up and uneven, this evidently greatly impeding the Polar Current in its course southwards along the coast. South of 75° N. Lat. the East Greenland continental shelf appears to be considerably narrower, a fact which naturally also has a good deal of influence upon the course of the current. On its farther course southwards, it is much impeded by the Iceland-Greenland Ridge and the extensive Iceland Submarine Platform and divides into two branches, *viz.* the Greenland Polar Current through Denmark Strait, and the East Iceland Arctic Current. On the eastern side of the Iceland Platform and just north of the Færoe-Iceland Ridge, there is a projecting ridge with depths of between 600 and 1000 metres, extending towards the north-east, which will probably have a checking effect upon the East Iceland Arctic Current.

To the north-east of the Færoes, our chart indicates another submarine elevation extending towards the north-east which would also have an effect upon the currents; but, as already stated, the existence of this bank is very doubtful.

Finally, we may also mention the volcanic cone of Jan Mayen, rising, with very steep slopes, in the middle of the Norwegian Sea Basin. It also has a great influence upon the circulation of this sea.

V. General Description of the Water-Masses of the Norwegian Sea.

As we pointed out above, the intermediate position of the basin of the Norwegian Sea, between the basins of the North Atlantic and of the North Polar Sea, is of vital importance for its oceanographic conditions. It forms the meeting-place of the waters coming from these two oceans, of which the physical conditions are so very different. In addition it also receives the coastal waters of the enclosed coastal seas of northern Europe—especially the North Sea with the Skagerak, the Kattegat, and the Baltic, and to some extent also those of the Barents Sea. The water-masses of the Norwegian Sea have, therefore, very different characters in the different, more or less sharply defined areas. But this is only in the upper water-strata, between the surface and say 400 or 500 metres, as a rule. Below this level, the Norwegian Sea forms an inclosed basin, which has very little communication with the adjacent seas. The water filling this deep basin has typical physical characters of its own, and shows a remarkable uniformity, thus forming a striking contrast to the heterogeneity of the overlying layers.

The water-masses entering the Norwegian Sea from different sides, at various depths between the surface and 500 metres, and thus being of very different origin, keep their physical characters for a long time and may be traced at a great distance from the place of their entrance. Where they meet, they will intermix more or less, and form waters with peculiar characters, which may be still more changed by the influence of various meteorological conditions.

In the Norwegian Sea there are consequently some waters whose characters originate from other parts of the Ocean (the Atlantic, the Polar Sea, the North Sea and the Baltic, and the Barents Sea), while other waters have aquired their typical characters in the Norwegian Sea itself. As examples of the latter, we may mention the waters of the central parts of the southern Norwegian Sea and of the northern Norwegian Sea (or the Greenland Sea) and also the Bottom-Water.

The Different Waters.

We think it will be as well to distinguish between the above-mentioned different kinds of waters, even if their limits are not in reality quite sharply defined; and we will therefore here briefly review the different groups of water-masses in question, and explain the terminology used in the following pages.

Atlantic Water enters the Norwegian Sea from the south, and has high salinities. With Prof. PETTERSSON, we generally consider as Atlantic water all waters having a salinity above 35·0 per mille, where-ever they may be found and whatsoever may be their temperature.

Coast-Water has salinities below 35·0 per mille, through admixture of river-water with the Atlantic water. In many cases we shall use the name coast-water, even where the salinity is only a little less than 35·0 per mille, and where consequently only very little river-water has been intermixed with the Atlantic water.

We may chiefly distinguish between two kinds of coast-water in the Norwegian Sea:

(1) *The European Coast Water*, forming a belt along the Norwegian coast. This is mainly formed by the rainfall and the melting of snow and ice from almost the whole of Northern and Central Europe, as far south as the Alps. This fresh water is discharged through the rivers into the North Sea and the Baltic, and the coast-water along the coast of Norway is a continuation of the currents coming from these seas. The variations in the temperature of this European coast-water throughout the year are very considerable.

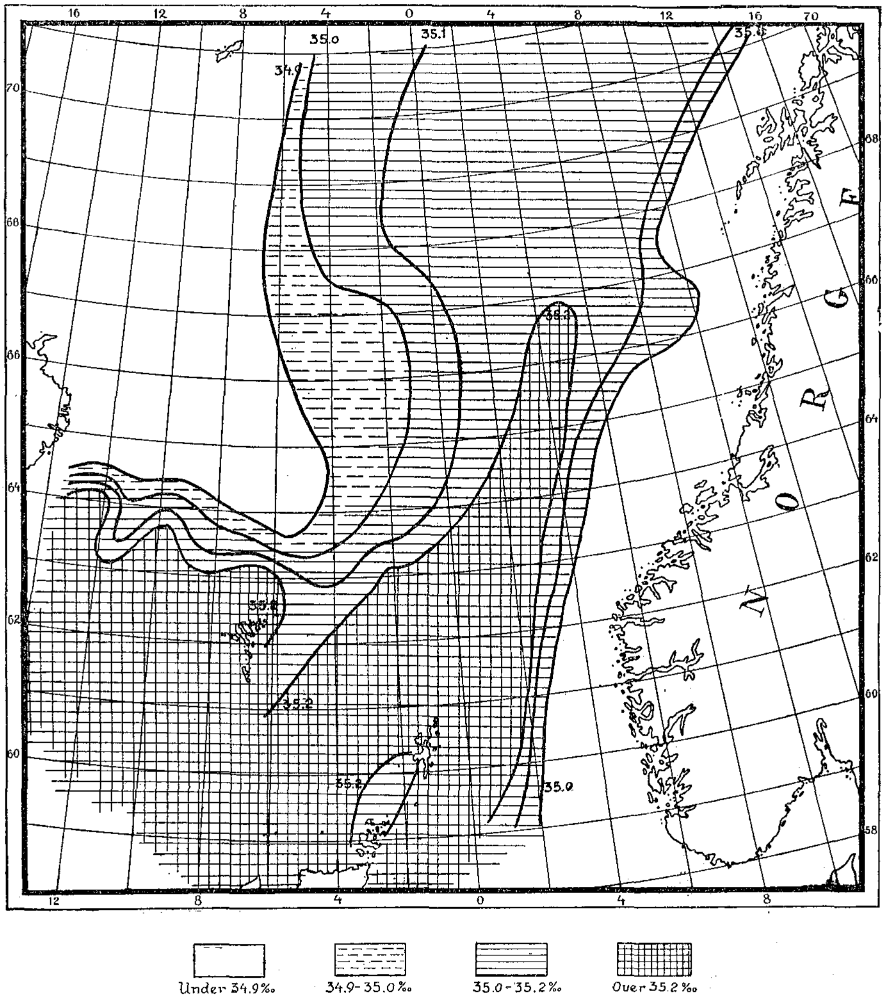

Fig. 9. Average Distribution of Salinity at 50 Metres, according to all observations taken during 1900—1904.

(2) *Secondly the Asiatic-American Coast Water*, generally called *the Polar Water*, covering the western part of the Norwegian Sea. It consists of river-water from north-eastern Europe, Asia to the north of the Altai, Yablonoi and Stanovoi Mountains, and from the north coast of North America, mixed with the waters (Atlantic and Coast-Waters) of comparatively high salinities running into the North Polar Basin from the Norwegian Sea and the Barents Sea. This coastal water forms the Polar Current that enters the Norwegian Sea between Spitsbergen and Greenland.

The Central Water-Masses occur in two areas, where they are formed. One of these areas is the central region of the *Southern* Norwegian Sea, between Iceland, Jan Mayen, and Norway, where these water-masses are bounded on the east and north by Atlantic water, and on the west by the East Iceland Arctic Current. The other area is the similarly central region of the *Northern* Norwegian Sea—between Jan Mayen, Greenland, and Spitsbergen—where it is surrounded by Atlantic water on the south and east and by Polar water on the west and north. These central waters are formed in both areas by the inter-mixture of Atlantic Water with Polar Water; they are comparatively stationary and are greatly influenced by the meteorological conditions prevailing in the areas in which they occur. The area of the northern central waters is the same as the so-called Bay-Ice Area. The salinities are below 35·00 pr. mille; being much the same as those found in great parts of the coast waters.

By the name of *Arctic Water* we call a special kind of Central Water which is formed by cooling in the Arctic parts of the Norwegian Sea (see later).

The Bottom-Water fills all the deeper parts of the Norwegian Sea Basin, and approaches the sea-surface in the region north of Jan Mayen, or between this island and Spitsbergen, where it is formed and acquires its peculiar characters, namely, its constant salinity of a little above 34·90 per mille, and its low temperature, this being below $-1\,^{\circ}$C.

The distribution of these various waters is the result of the currents, and thanks to our present knowledge of this distribution, we are now fairly well acquainted with the entire current-system of the Norwegian Sea.

At the beginning of our investigations we expected to be able to trace distinctly certain more or less regular variations, annual and seasonal, in this system, and we even hoped to discover the laws that regulated these variations; but although we have succeeded to some extent in our aims, we have on the whole been disappointed. This is due to the oceanographic conditions themselves, the local variations and the irregularities of the currents predominating so greatly, that they more or less hide the periodical variations. This is shown by our series of observations from 1900 to 1904. Owing to unavoidable circumstances, our observation-material could not be made so complete as we could have desired for a detailed study of these variations.

2. Regularity in the Vertical Distribution of Density in the Sea.

As Nansen has already pointed out in his preliminary report [1901, pp. 141 and 149], our investigations during the first cruise, in 1900, gave us a perfectly new idea of the distribution of salinity and density in the Norwegian Sea, as well as in the Ocean in general. The regularity with which, for instance, the density gradually increases vertically, from the surface of the sea towards its deeper strata, where it becomes almost uniform, is striking. This is clearly demonstrated by vertical curves of density, drawn for any of our stations. At a few stations, exceptions, with slight irregularities, appeared to occur, where heavier water apparently rested on lighter water; but our investigations of later years prove, on the whole, that the more accurately the observations are made, the fewer are the exceptions met with of this kind. Our many thousands of observations from the Norwegian Sea all go to prove that the changes in the vertical distribution of density in the open Ocean are generally gradual, and therefore that the sudden and often puzzling irregularities, great and small, which occur in nearly all vertical series of observations of previous expeditions, must be chiefly due to errors of observation.

Numerous and striking irregularities of this kind also occur in the determinations of the densities of the Norwegian Sea, based upon the observations of the Norwegian North Atlantic Expedition in 1876—1878. Owing to errors made by the chemists of this expedition, MOHN found that the heavier water rested on the top of lighter water in many places, and at all depths; and he consequently constructed a whole system of vertical currents formed by rising lighter water and sinking heavier water. Our observations, in 1900 and subsequent years, prove that none of these currents exist, and the whole system has therefore to be relinquished as it was based exclusively

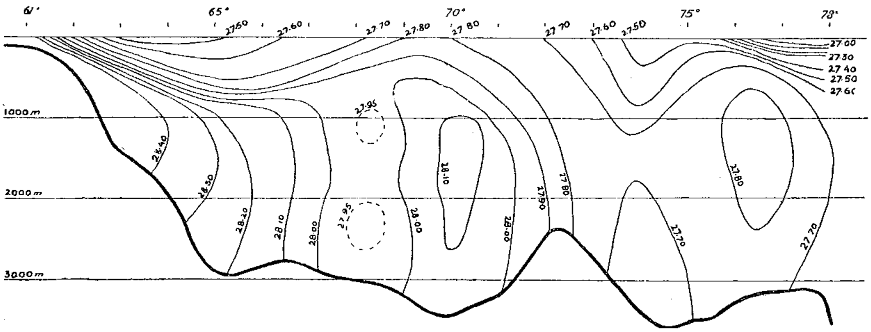

Fig. 10. Section from the Shetland Platform along the Greenwich Meridian to 78° N. Lat., representing the Vertical Distribution of Density according to MOHN [1887, Pl. XLI].

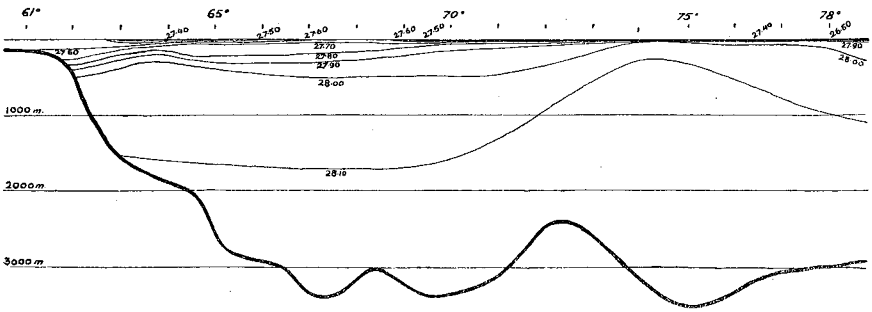

Fig. 11. The Same Section according to Recent Observations.

on erroneous observations. The alteration of our views in this respect, necessitated by the facts as revealed by our more accurate observations, may be seen by a comparison of Figures 10 and 11.

Fig. 10 is a reproduction of MOHN's meridional section XXVIII, showing the vertical distribution of density in the Norwegian Sea along the Meridian of Greenwich from the Shetland Platform northwards to Latitude 78° N. [MOHN, 1887, Pl. XLI]. Fig. 11 is a similar section of the Norwegian Sea, along the same meridian, based upon our observations.

The difference in the distribution of the densities in these two sections is striking; hardly a single feature can be found which is common to both sections, and even the densities themselves are everywhere different. MOHN, indeed, would have been much better off if he had had no observations of the salinities (or specific gravities), and had only based the construction of his isopyknals on the observations of temperature, assuming a uniform salinity throughout the whole sea-basin.

Mohn's densities (σ_t) vary, even in the deeper strata, between 28·40 and 27·95, while no such variation can possibly exist anywhere in the Ocean in deeper strata. Our section, Fig. 11, shows that the greatest variation below a depth of say 1000 metres is between 28·08 and 28·12. In Mohn's section we find densities of 28·40 even near the sea-surface over the Shetland Bank. Such a high density is not known to exist anywhere in the open Ocean, not even in its deepest and heaviest strata(1). If Mohn's densities of the waters over the slope of the Shetland Bank had been even approximately correct an enormous fall of water must needs have been formed by the rapid sinking of the heavy waters towards the deep hollow of the Norwegian Sea Basin(2). But in reality nothing of the kind exists; on the contrary, the waters over the slopes of the Shetland Bank are lighter than those of the upper strata farther north, and Fig. 11 shows clearly that the density of the upper strata of the Norwegian Sea increases with comparative regularity northwards. Instead of Mohn's isopyknals that run in all possible directions, very often almost vertically from the strata near the sea-surface towards the bottom, the isopyknals of Fig. 11 (drawn for the same intervals of the value of σ_t, *viz.* 0·1) nearly all of them lie above the 600 metres' level and run more or less horizontally, gradually rising, on the whole, towards the north. Our isopyknals also demonstrate everywhere the gradual increase of the density from the sea-surface towards the deep strata of the bottom-water where it is nearly uniform.

The only cases in which we know with certainty that heavier water may rest for a short while on the top of lighter water, are when the surface-water of the sea is cooled by the radiation of heat,

(1) The only region where sea-water with densities approaching this value has been observed, is the Barents Sea, where an exceptionally heavy bottom-water (σ_t = 28·33) has been observed; but this high density is produced by the formation of ice under peculiar local circumstances (cf. Nansen, 1906, p. 40, and pp. 30—34) which cannot occur to the same extent in the open Ocean.

(2) We have not been able to find out how Mohn has obtained his abnormally high densities near the surface in this region of the sea, as they do not at all agree with the distribution of temperature and salinity as demonstrated by his own sections, Pls. XIV and XXXVIII.

especially during winter and spring, and vertical convection currents are formed; and when the salinity of the surface-strata is greatly increased by the formation of ice; but even in these cases the differences of density between the overlying and underlying strata, are always very slight, the convection currents, or vertical *circulation*, being evidently started as soon as the condition of unstable equilibrium has been reached.

In the deepest strata of the cold bottom-water, the differences of density (see Chap. XI), are so small, that even the best methods now existing, do not demonstrate them with sufficient certainty. A small increase of density in the upper parts of these strata would give rise to vertical currents throughout the whole under-lying body of water. This is probably sometimes the case in the areas north of Jan Mayen, where the bottom-water is formed; but the differences of density (and salinity) have been found, since 1900, to be so slight that this bottom-water may be used almost as a standard water for controlling the accuracy of the observations of previous expeditions in the Norwegian Sea. If, for instance, we assume that the observations of salinity made during an expedition have been erroneous, the errors may be discovered wherever the investigations have reached down into the bottom-water. When the observations of previous expeditions are tested in this manner, it unfortunately becomes evident that in most cases the errors are very irregular, and the observations are consequently of little value [cf. NANSEN, 1906].

VI. Apparent Irregularities in the Horizontal Distribution of Temperature, Salinity, and Density.

1. Puzzling "Waves" of the Equilines in Vertical Sections.

We have already pointed out that there are often great variations or irregularities in the horizontal distribution of the temperature, salinity, and density in the upper strata of the sea—at any rate down to 600 metres, and probably much deeper —which make it much more difficult than has hitherto generally been believed, to obtain trustworthy representations of the volumes of the different kinds of water; they certainly cannot be attained by observations at a small number of isolated stations, chosen more or less at random. Such irregularities, great or small, are seen in most vertical sections where the stations are sufficiently numerous and not too far apart. The equilines (isotherms, isohalines, as well as isopyknals) of the sections hardly ever have quite regular courses, but form bends or undulations, like waves, sometimes great, sometimes small.

When, in 1901, Helland-Hansen first found a great wave of this kind in the sections across the Norwegian Atlantic Current, he thought that it indicated some kind of permanent division of the current longitudinally, into two branches. But by continued research with more stations, even several "waves" were sometimes found in the same sections, and it soon became evident that they could not indicate any such division as he had at first thought, but must have some other hitherto unknown causes. In some cases the steep inclinations of the isopyknals even proved that a considerable amount of energy would be required to produce the "waves".

Good examples of such "waves" may be seen in the section off Aalesund in February, 1901 (Pl. XV, Fig. 1), the section off Feje in May, 1901 (Pl. XVI, Fig, 1), the section off Feje in May, 1902 (Pl. XVII, Fig. 1, Stat. 5), the section between the Sognefjord and Iceland in August, 1903 (Pl. XXII, Fig. 1, Stat. N 5), and the sections off the Sognefjord and off Stad in May and June, 1904 (Pl. XXIV A, Figs. 1 & 2).

The shapes of the isopyknals of the sections prove that these "waves" cannot represent permanent or stable conditions, unless they are formed by some permanent force. It is more likely that, in most cases, they are more or less temporary formations, due to some kind of movement of the intermediate water-masses which we do not yet know(1).

It is a striking fact, and apparently not merely an accidental one, that by far the greatest "waves" of this kind in our sections, occurred in 1901, when the atmosphere was unusually stormy; and it appears probable that the "waves" in that year might have been due to stirring of the water-masses, caused by disturbances in the atmosphere.

2. Possible Causes of the "Waves".

The knowledge of the exact nature and causes of these "waves" and their movements would, in our opinion, be of signal importance to Oceanography, and as far as we can see, it is one of its greatest problems that most urgently calls for a solution.

The material at hand is certainly not sufficient for a thorough study of these "waves"; but we may give some indications how such "irregularities" may possibly arise.

(1) Professor F. L. EKMAN has given a figure [1875, p. 95, Fig. 6] representing a section of a current, in which there is an upward bend on the under side, which apparently resembles our "waves". But this is caused by the convection currents arising in a current of homogeneous water by cooling from contact with colder water at the sides, and has therefore no real resemblance to our "waves".

By a careful study of all the observations at our disposal, we have come to the conclusion that apparent irregularities in the sections, of the kind mentioned, may be caused in at least three ways: by *boundary waves* in the water-strata at intermediate depths—by *sudden variations in the velocity or direction of the surface-currents*—and by great *vortex-movements* in the sea.

a. Waves in the Intermediate Water-Strata.

In April and June, 1894, during the Fram-Expedition across the North Polar Basin, Nansen observed peculiar oscillations in the temperature of the water at depths of about 200 and 300 metres, near the boundary between the intermediate warm stratum and the overlying colder stratum. He thought [1902, pp. 346—351] that these changes of temperature, occurring at short intervals of time, at the same depths, were probably due to vertical movements of the water of some kind; either small vortices with horizontal axes, which are generally formed by friction where one water-stratum glides on the top of another—or intermediate waves, occurring at the boundary between water-strata with different densities. By such waves, the upper boundary of the underlying heavier (and in the above case warmer) water would be alternately raised and lowered, at certain intervals; and the depth at which the boundary is found, at a certain moment, will depend on the time of the observation, whether one just happens to be near the crest or the trough of the wave. The heights of the waves in the above cases may have been 30 or 40 metres.

Our later observations make it appear, in our opinion, very probable that the latter explanation is correct, and show that such "boundary waves" may occur, and cause apparent irregularities, where the water-strata overlying each other are fairly sharply defined.

On April 15th, 1894, a temperature of 0·51 ° C. was observed at 250 metres (Fig. 12). A similar high temperature was otherwise never observed at that or any other depth, in that region of the sea. It has probably been the temperature of a warm water-stratum, which on the other days (April, 21 and 23) might have been either higher or lower, and was never struck, being at levels between those of the observations. On April 23rd, three observations were taken from 250 metres at different times of the day. Only one of them, giving 0·35 ° C., approached that of April 15th (giving 0·51 ° C.), while the two other observations gave lower values (0·15 and

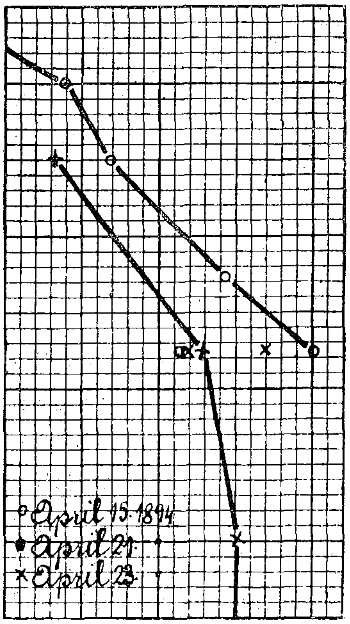

Fig. 12. Vertical Temperature-Curves for April 15, 21 & 23, 1894. North Polar Basin. [NANSEN, 1902, p. 349].

0·09 ° C.); and on April 21st, a still lower temperature (0·07 ° C.) was observed at the same depth. The distance between the observation-stations cannot explain these variations in temperature, as there was hardly a mile between April 21st and 23rd; but between April 15th and the two other days there were some twenty miles.

It is not probable that a vertical vortex-movement (*i. e.* with horizontal axis) could on April 15th, have raised the warm water-stratum with the maximum temperature (0·51 ° C.) to 250 metres, from about 280 or 290 metres, where it probably was on April 21st and 23rd, when the temporatures of 0·07, 0·09, and 0·15 ° C. were observed at 250 metres; for if the water-strata were frequently stirred by so great vertical movements of this kind near their horizontal boundaries, they would soon be intermixed, and we could not expect to find them so sharply defined horizontally, especially in the region north of the New Siberian I slands, where no new intermediate currents enter the North Polar Basin.

It is also improbable that the different temperatures observed at the same depth belonged only to small volumes of water, some warmer and some colder, situated side by side; for they would probably long before have been intermixed to form a more homogeneous horizontal water-stratum.

The most feasible explanation, according to our view, is therefore, that the above changes of temperature, observed at the same depths, are due to oscillatory movements of the horizontal water-strata, at intermediate depths; and owing to their difference of density, these strata rest one on the top of another for a very long time, with more or less sharply defined boundaries horizontally. Their intermixture takes place only very slowly, and the greater the difference between their densities, the slower will they intermix(1).

(1) If horizontal vortex-movements (with vertical axes), like those we are going to mention later, occur in the intermediate strata, they may cause considerable changes in the level of the boundaries between the several strata; but we do not think that the above apparent oscillations can be thus explained. They could not then be expected to be of such a short duration as only some hours, for the vortices can hardly change place so rapidly.

These intermediate water-strata are always in undulatory motion, owing to variations in the surface current (*e. g.* the tidal variations, cf. p. 113) or owing to boundary waves. These waves move comparatively slowly, and may be of very great dimensions; for they advance in a medium with only slightly lower density. We have seen that, in the above cases, the heights of the oscillations may have been 30 or 40 metres; but the boundary waves are probably sometimes much higher, especially if moving in strata at great depths below the sea surface.

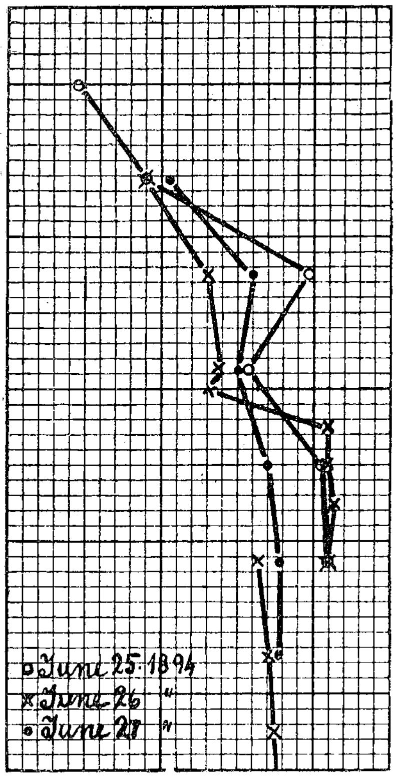

Fig. 13. Vertical Temperature Curves for June 25, 26 & 27, 1894. North Polar Basin [NANSEN, 1902, p. 349].

The vertical temperature curves for June 25th, 26th, and 27th, 1894 (Fig. 13), also exhibit certain interesting peculiarities [cf. NANSEN, 1902, p. 349]. The ship hardly moved four miles in those three days. The curve for June 25th shows two maxima of about 0·5 ° C., one at about 250 metres, and another at 300 and 325 metres. It is possible that these maximum temperatures belonged to the same warm water-stratum, which had been lifted to 250 metres when the observation from that depth was taken, while at other times it was lower. The fact is that the two observations from 300 and 325 metres were taken in the afternoon and evening, while the observation from 250 metres was taken earlier in the day. The observations taken from 290, 300, 310 and 325 metres in the afternoon and evening of the following day (June 26th, between 6 p. m. and 7.30 p. m.) give maximum temperatures almost identical with those at 300 and 325 metres as well as at 250 metres of the previous day; while the observations taken at similar depths in the morning of the same day and the day following (June 26th, 10 a. m. at 300 metres; 9·30 a. m. at 325 metres; June 27th, 11 a. m. at 325 metres) give nearly uniform, low temperatures. The warmest water-stratum may then have been lifted to a higher level, and the low temperatures may have been taken in the colder water below this stratum. We might consequently expect that at 250 metres the observations would give higher temperatures in the morning than in the afternoon. This was also the fact. The lowest temperature at that depth was observed on June 26th. 5 p. m. while the highest was found on June 25th, in the morning. The temperature observed on June 27th, 10.10 a. m., was between the two values, but the observation may possible not have struck the warmest stratum. Four observations taken at 275 metres give comparatively low temperatures, the lowest being taken on June 26th, 5.30 p. m., when the warm water stratum was probably lower, whilst the others were possibly taken when this stratum was lifted higher(1).

The observations of the specific gravity of the water-strata were unfortunately not sufficiently accurate, nor sufficiently numerous, to give trustworthy information with regard to the salinity of these different water-strata.

There is a possibility that such vertical movements of the intermediate water-strata, underlying the lighter top-layer, might be caused by boundary waves which have some connection with the tidal waves of the North Polar Basin. We have also concidered the possibility of stationary waves of some kind; but we cannot see that such great oscillations can be thus accounted for according to our present, rather imperfect knowledge of the different kinds of stationary waves. Boundary waves give the easiest explanation, if we assume that there is a regular (repeated) impulse creating the waves, whether this impulse be the Atlantic tidal waves (*e. g.* entering the basin over a ridge) or pulsations of the current (see later). But the observations are too few for a study of these oscillations, and for a determination of their period.

During our cruise in 1900 we had our attentions directed towards this problem; but we found no place with conditions favorable for a study of it, where sharply-defined water-strata with sufficient difference of density were resting one on the top of another; and we therefore observed no such oscillations with long periods. We found, however, another kind of *oscillations with very short periods*, which may also be of importance.

At Stat. 15, Aug. 5, 1900, north of Iceland, this kind of oscillation occurred, and the following observations were taken:

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(1) It is, however, a striking fact that all the observations of temperature taken between 250 and 300 metres, on June 27th, are lower than the maximum temperatures observed at those depths on June 25th, and 26th. This might be due to the fact that the ship had drifted somewhat towards the south, but it may also be that on the morning of June 27th, the stratum with maximum temperature was not struck by the observation, it may, for instance, have been between 225 and 250 metres. The series of that day, however, may indicate that there have actually been two maxima.

Observations at Stat. 15, Aug. 5, 1900. 66° 45' N. Lat.; 15° 36' W. Long.

Hour	Depth in Metres	t ° C.	S ‰	σt	Hour	Depth in Metres	t ° C.	S ‰	σt
10.40 a. m.	0	6·8	33·88	26·59	1.15 p. m.	20	4·81	34·14	27·04
10.55 —	20	·26	·91	·68	18 —	—	·64		
0.05 p. m.	25	4·75	34·14	27·04	21 —	—	5·26		
11.55 a. m.	30	3·20	·33	·35	25 —	—	·21		
11.05 —	50	2·20	·57	·63	30 —	—	·22		
11.20 —	100	·30	·67	·70	33 —	—	·03		
11.30 —	150	·47	·74	·75	35 —	—	·02		
11.45 —	200	·39	·77	·78	3.40 —	—	6·02		
10.55 —	20	6·26	33·91	26·68	45 —	—	5·87		
1.10 p. m.	—	·20			50 —	—	6·52	33·95	26·68

The temperature fell very rapidly between 20 and 25 metres while at the same time the salinity rose, the water-strata being evidently very sharply defined at that level. But the numerous observations taken at 20 metres show that there must have been much vertical movement of the water at this depth, for at one time, *e. g.* at 1.15 p. m., we would find water with a temperature of 4·81° C. (even 4.64° C. at 1.18 p. m.) and a density of 27·04, while at other times there was water with a temperature of 6·26° C. and 6·52° C., and a density of 26·68. The great difference in density shows that there cannot have been a heterogeneous mixture of different waters lying side by side; but there must have been a vertical oscillatory movement, of some kind, which at certain intervals has raised and lowered the water at 20 metres. Fig. 14 (a) gives an idea as to what the vertical distribution of temperature may have been at different moments of these oscillations. At one moment when the highest temperature (6·52° C.) was observed at 20 metres, the vertical curve of temperature may approximately have had the shape of the lower curve for Stat. 15 (Fig. 14 a'), while it may have had the shape of the uppermost curve (Fig. 14 a"), when the lowest temperature (4·81° C.) was observed at 20 metres. If this assumption be correct the oscillatory movement may possibly have raised and lowered the water with a temperature of 4·8° C., to the extent of about 10 or 15 metres, or even more.

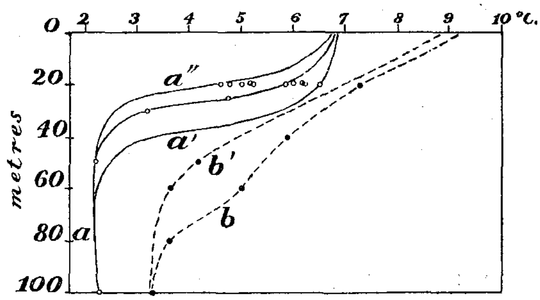

Fig. 14. Vertical Temperature-Curves at Stat. 15 (a) and Stat. 9 (b), 1900.

The changes in the water-temperature at 20 metres often occurred at very short intervals. For instance in the space of five minutes, from 1.10 to 1.15 p. m., the temperature had changed from 6·20° C. to 4·81° C. Other observations show less difference — *e. g.* between 1.21 and 1.35 p. m. only from 5·26° C. to 5·02° C. The explanation may be that the period of the wave was only a few minutes and we were neither near the crest nor the trough of the wave when the latter observations were taken; but the oscillations may also have been irregular, great and small, with various intervals.

Helland-Hansen has recently found similar changes with very short periods in the currents, by current-measurements in the fjords near Bergen (cf. Chapt. VIII).

Some observations at other stations of the cruise of 1900, show similar changes in the temperature of the water at depths between 30 and 100 metres (*e. g.* see Table: Stat. *7*, 30 and 40 metres; Stat. *8*, 30, 50 and 100 metres; Stat. *46*, 50 metres). Observations taken at hours differing from those of the other observations of a vertical series often show conspicuous irregularities, when introduced into the series along with others.

Stat. 9, of July 25th, 1900, may be mentioned as an example. Most observations, between 0 and 100 metres at this station, were taken between 11 p. m. and midnight on July 25th. They give a very regular vertical curve of temperature (Fig. 14 b); but this regularity is broken if we introduce into the curve two temperature-observations taken at 50 and 60 metres, three hours later (at 3 and 3.15 a. m., July 26th). It is probable that the water-stratum found at 60 metres at 3.15 a. m., (Fig. 14 b') had been at about 80 metres at midnight (Fig. 14 b); this is indicated by both the temperature and the salinity. The two observations at 60 metres gave different densities, 27·73 and 27.90, which would easily be explained by oscillations of the kind mentioned(1).

During the cruise in June and July, 1902, between western Norway and the Færoes, along the continental slope of the North Sea Platform and the Færoe Platform, considerable variations, in temperature and salinity, were often observed in the bottom-waters at short distances and at the same depths, which might indicate vertical oscillations of the bottom-strata; but they may also have been due to local differences.

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(1) In regions where waters of different origin meet, a heterogeneous mixture of waters, with different temperatures and salinities, but with nearly uniform densities, may occur. Small volumes of these different waters may exist for some time side by side at the same level, as they are in equilibrium, and will intermix only very slowly by diffusion, to form a more homogeneous mixture.

Stat. 29, of Aug. 9th, 1900, is a good example of such a place. Five observations were taken from 100 metres giving very different temperatures and salinities, but nearly uniform densities. Two observations were taken from 150 metres showing similar conditions (see Table). The variations observed at the same depth in these cases cannot therefore be due to vertical oscillatory movements of the water-strata, but simply to the horizontal motion, either of the ship, or the water. When there is a vertical oscillatory motion, we must expect to find variations in the density.

Only on one or two occasions were the bottom-observations repeated on exactly the same spot, but even then changes were observed.

On June 29th, 1902, a station (Stat. 38, see Pl. XIX, Fig. 1) was taken on the continental slope in 62° 20′ N. Lat., 1° 56′ E. Long., just at the mouth of the Norwegian Submarine Channel. Near the bottom, in about 503 metres, Helland-Hansen found, at about 4 p. m., a temperature of between 2 and 3° C.(1) He consequently told the zoologists that they would there find a bottom-fauna belonging to the warm area, but to their astonishment the animals brought up by the dredge all belonged to the cold area. A new bottom-observation was now (at 10 p. m.) taken, giving a temperature of — 0·07° C. at 550 metres, which was in good harmony with this fact, but contrasted markedly with the observations taken 6 hours earlier, almost on the same spot. The ship had in the mean time only moved so much as the dredging required, and the depth was somewhat increased from 503 to 550 metres. But this was not sufficient to explain the great change in the temperature. We consider it probable that, when the latter observation was taken, the cold bottom-layer had been considerably raised, perhaps by a boundary wave, or by variations in the surface-current (cf. p. 113).

The following examples of remarkable changes at the same levels, at the same place, or at places with very short distance between them, may be given.

Station & Date. 1902.	Latitude & Longitude.	Hour.	Depth in Metres.	t° C.	S ‰.
Stat. **56**	62° 33′ N.	4.43 p. m.	200	6·53	35·17
July 19.	2° 3′ E.	4.38 —	300	5·27	
		8.25 —	300	5·83	35·14
		4.16 —	400	3·23	34·99
		4 —	450	1·90	34·92
		8.15 —	460	1·92	34·94
Stat. **38**	62° 30′ N.	4.36 p. m.	200	6·89	35·20
June 29.	1° 56′ E.	4.0 —	300	6·17	35·17
		10.10 —	300	6·25	35·17
		4.15 —	400	4·91	35·08
Stat. **51**	61° 40′ N.	7.8 p. m.	400	6·34	35·24
July 15.	3° 11′ E.	8.22 —	400	6·52	35·25
Stat. **66**	62° 29′ N.	6.34 p. m.	625	0·99	34·96
July 27.	4° 12′ W.				
Stat. **67**	62° 35′ N.	9.30 p. m.	620	0·03	34·92
July 27.	4° 4′ W.				

(1) The mercury thread of the Nansen Deep-Sea Thermometer of the insulated water-bottle had been divided and the temperature could not be accurately determined. Therefore, it was unfortunately not introduced in the journal, as it was intended to repeat the observation later.

The depths were at Stat. 56 455—460 metres, at Stat. 38 503—548 metres, at Stats. 66—67 613—630 metres. The two latter stations were on the continental slope, off the north-east corner of the Færoes. The observations indicate great variations in the levels of the strata, which can hardly be explained only as due to local differences.

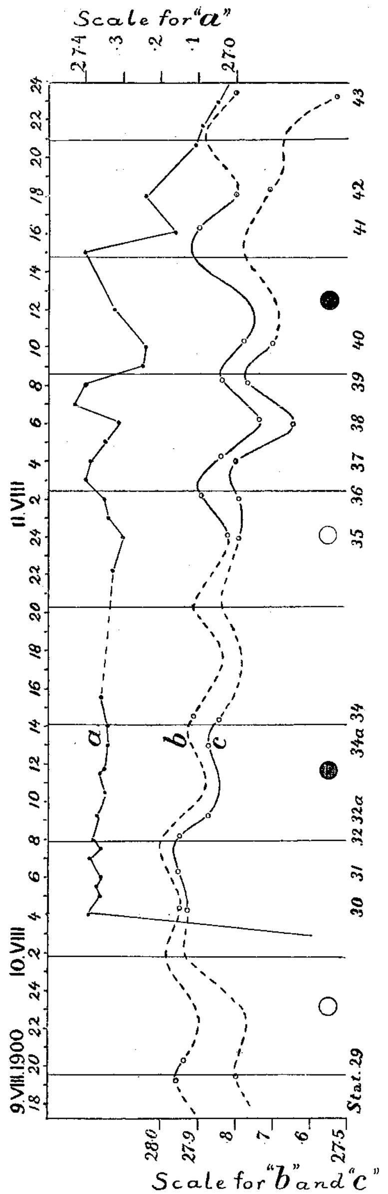

Fig. 15. Part of Section between Jan Mayen and Vesteraalen, August, 1900. Density-curves: *a* for Surface, *b* for 100 Metres, *c* for 50 Metres.

It is to be expected that such vertical oscillations always occur along the continental slope. These frequent changes between cold and warm waters must have a distinct influence upon the characteristics of the bottom-fauna at these boundary levels.

If our conclusions be correct, namely, that *oscillatory movements or "boundarys waves" with long periods*, like those observed in the North Polar Basin, occur in the sea, it seemed to us possible that some indications of such waves might be found in the vertical sections across the Norwegian Sea, provided that the stations were taken at sufficiently short intervals. But unfortunately in none of our sections are the stations sufficiently numerous for this purpose.

One of the best is perhaps a part of the section between Jan Mayen and Vesteraalen, August, 1900 (cf. Pl. III & XIV A, Fig. 2). In Fig. 15, we have drawn the probable curves for the variations in the density at 50 metres (*c*) and at 100 metres (*b*) in a part of this section, between Stat. 29 and Stat. 43.(1) The observations are

(1) The stations are marked at their proper places along the foot of the figure. The hours are given along the top by figures from 1 to 24, reckoned by the civil day from midnight to midnight.

not sufficiently numerous to give trustworthy curves; but we think that they may indicate a period of very nearly 6 hours and a quarter (half the period of the tidal wave) both at 50 and 100 metres. During August 11th the observations (marked by a small ring on the curves) are so numerous that it looks as if the curves could hardly be drawn otherwise. The hours of the upper culminations of the moon are indicated by rings and that of the lower culminations by black discs. Every second minimum of the curves appears to occur just a little before each culmination of the moon.

During the cruise of the *Michael Sars* in May & June, 1904, many stations were taken at sufficiently short intervals of time to allow the observations to demonstrate oscillations with long periods should they exist.

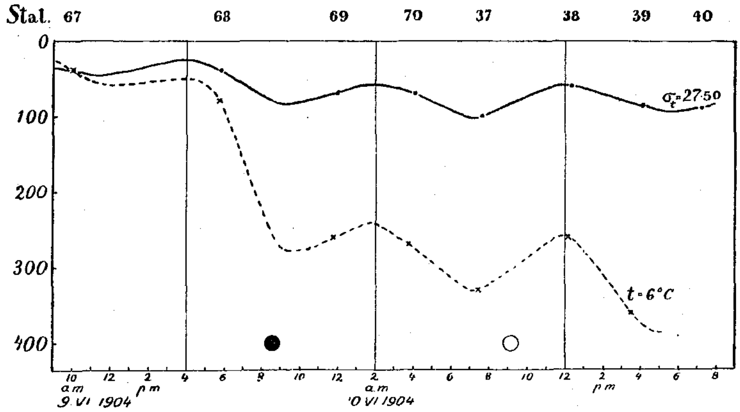

Fig. 16. Part of section seawards from Stad, June, 1904 (cf. Pl. XXIVA, Fig. 2).

Fig. 16 represents the undulations of the isopyknal of 27·50 and the isotherm of 6° C. in the section seawards from Stad, from June 9th & 10th, 1904. The depth (between 0 and 400 metres) is given along the ordinate, and the hour, along the abcissa. The observations appear to indicate a periodical oscillation, the period being

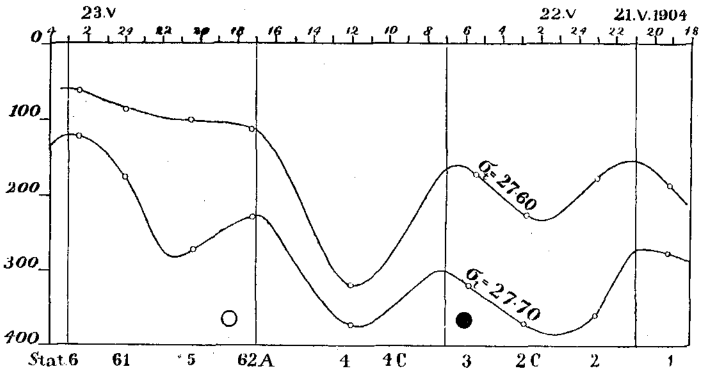

Fig. 17. Part of Section seawards from Sognefjord, May, 1904 (cf. Pl. XXIVA, Fig. 1). The dates and hours run from right to left.

about 10 hours. But unfortunately, at least one of these apparent "periodical oscillations" in the section, between noon and midnight on June 10th, is probably due to a horizontal vortex-movement of the waters, as will be mentioned later (cf. Fig. 37), and has consequently not been an oscillation of the kind we are discussing at present. This is a warning against being too hasty in drawing conclusions from a small number of observations.

The isopyknals of 27·60 and 27·70 in the section seawards from the Sognefjord (Fig. 17) exhibit, however, indications of a similar periodical oscillation of 10 hours, between May 22nd, 7 p. m. (19) and 23rd, 2 a. m., 1904; but in this case there is also a possibility of vortex-movements being the real cause of the appearance of periodical oscillations.

Oscillations shown by Surface-Observations.

Having found that such oscillatory movements probably occur in the intermediate strata of the sea, we thought it would be interesting to find out whether any kind of periodical oscillation could be discovered in the variations of the surface-observations. It has of course to be remembered that the values of temperature and salinity of the surface-observations depend very much upon the manner in which they are taken. If, for instance, a bucket be used while the ship is going at full speed, it may make a difference whether this bucket is filled simply by letting it skim the water-surface, or by throwing it forwards and letting it sink far below the surface before it is hauled on board. If there be much difference between the strata near the surface, or if, for instance, there had been a rainfall just before the observations were taken, and there had been no strong wind to stir the upper water-layers, it is clear that a considerable difference between the water-samples might result from these two methods of taking the samples. In order to trace any kind of periodical oscillation, therefore, it would be important to have series of surface-observations taken at short intervals, and all of them exactly at the same depth, *e. g.* 1 metre below the surface. They ought also to be taken all at the same place, because observations from a moving ship will naturally show local variations in the sea, which may be much greater than those caused by the oscillations. But having had no opportunity of collecting such an ideal observation-material, we have examined the observations at our disposal.

In Fig. 15 we have introduced the curve of the surface-density (a). It shows great variations, but no certain periodicity arising from regular oscillations can be traced, not distinctly at any rate, although a few of the greatest variations, *e. g.* the maxima at the hours 7—8 and 15 on Aug. 11th, appear to coincide to some extent with those of the curves for 50 and 100 metres; but the coincidence is not so marked but that it may not be accidental. It is worthy of note that the maxima of the surface density at the hours 3, 7—8, and 15, on Aug. 11th, are due to lower temperatures, while the salinity shows in the first case no increase, and in the two latter cases even marked decreases. This strenghtens the probability that the maxima of surface density have not been due to a lifting of lower strata to the surface, but have been caused by surface-water coming from the north, or, *vice versa,* the minima by water coming from the south.

It might, however, be possible that the conditions near the sea-surface are too uniform in the region of our section, between Jan Mayen and Vesteraalen in 1900, to show much variation. If regular oscillations exist they might be easier to trace in regions where there are greater differences between the surface strata. The sea along the north coast of Iceland, and between Iceland and Jan Mayen, are such regions, and the curves of surface-salinity, as also of surface-density, from our voyage through this sea, between August 3rd and 7th, 1900, exhibit very great and peculiar variations, as shown by Fig. 18. The numbers of the stations are given along the foot of this figure, and Pl. III, Figs. 1 and 2, shows the position of the stations, and our track [cf. also NANSEN 1901, Pl. I].

The great variations of the curves may to a great extent have had local causes. The conditions between Stat. 14 and Stat. 15 are a special instance of this, the rise in density being there accompanied by a rise in salinity and a fall in temperature, making it evident that each fall of density and salinity in this part of the curve has been caused by the Iceland coast water, whose distribution is greatly dependent on the configuration of the coast and that of the continental shelf. It is evident that the variations along this part of the route have been chiefly due to such causes, and this fact has consequently to be carefully considered in an attempt to trace any period in the variations. Between Stat. 17 and Stat. 20, in the sea between Iceland and Jan Mayen, each fall in density is also accompanied by a fall in salinity, but frequently also by a fall in temperature, which proves that it has been caused by polar surface-water, and not by coast-water. It cannot but be expected that variations shown by these curves, would be very irregular, and it is certainly not easy to trace any period in them; but nevertheless there are perhaps indications of some relation between the culminations of the moon and the minima of the latter part of the curves, though this is much too indistinct to allow of our saying anything with certainty.

Fig. 19 represents the curves of surface-salinity (broken line S ‰) and surface-density (σ_t) in the Norwegian Sea north-east of Iceland, between May 11th (4 a. m.) and 16th (10 a. m.), 1901. The region of these surface-observations is the so-called Bottle-nose Area, where the bottle-nose whale (*Hyperoödon diodon*) is caught; and the ship was most of the time in the sea north of Stat. 14 (se Pl. V). In this region, near the boundary of the East Iceland Arctic Current, there are frequent variations in the surface-layers, and our curves prove that the rise and fall of density coincide almost exactly with those of the salinity. It is a striking fact that, with very few exceptions, the culminations of the moon coincide with maxima of density and salinity. But, as was also the case at 50 and 100 metres in our section of Aug., 1900 (Fig. 15),

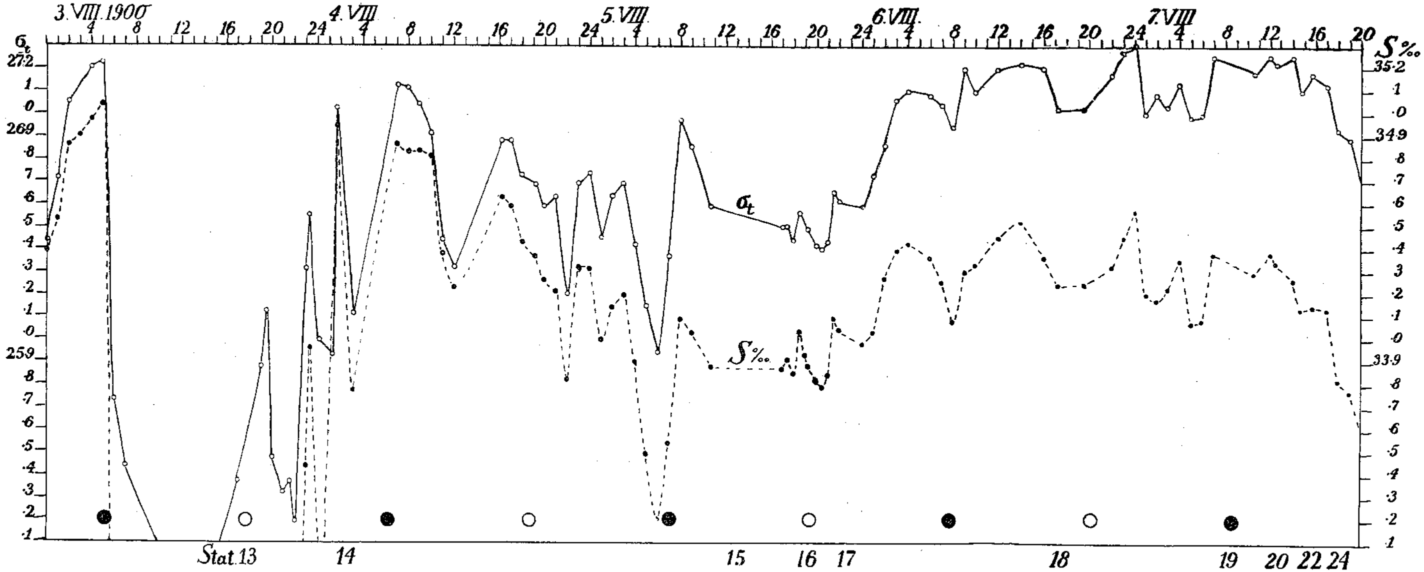

Fig. 18. Curves of Surface-Salinity ($S\,^0/_{00}$) and Density (σ_t). August 3rd, 0 a. m.—7th, 8 p. m. (20), 1900. Sea north of Iceland (cf. Pls. III & XIV B, Fig. 1).

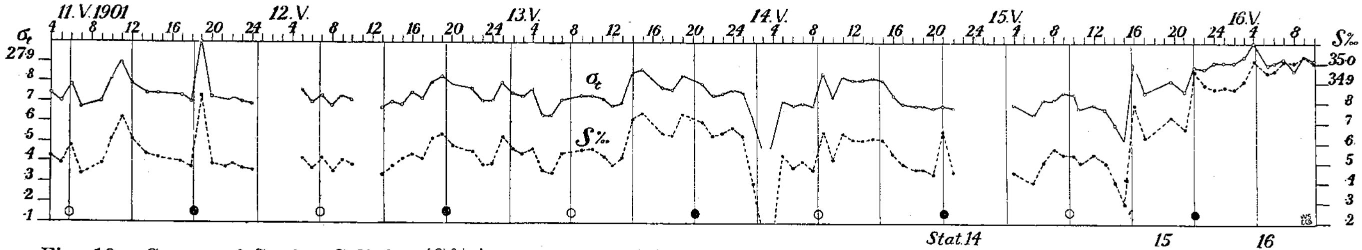

Fig. 19. Curves of Surface-Salinity ($S\,^0/_{00}$) and Density (σ_t), May 11th (4 a. m.)—16th (10 a. m.), 1901. Bottle-Nose Area.

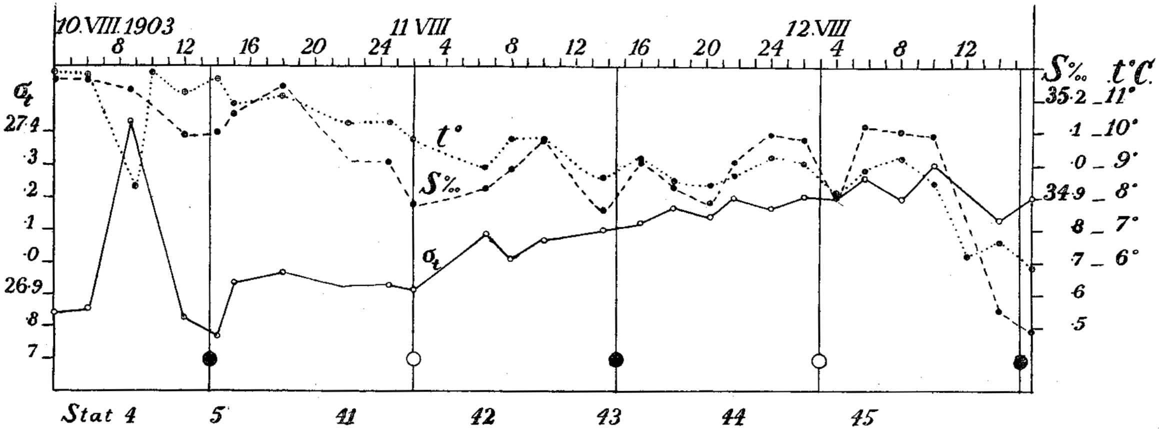

Fig. 20. Curves of Surface-Temperature ($t°$), Salinity ($S\,°/_{00}$), and Density (σ_t). August 10th—12th, 1903. Southern Norwegian Sea, between Norway and Iceland.

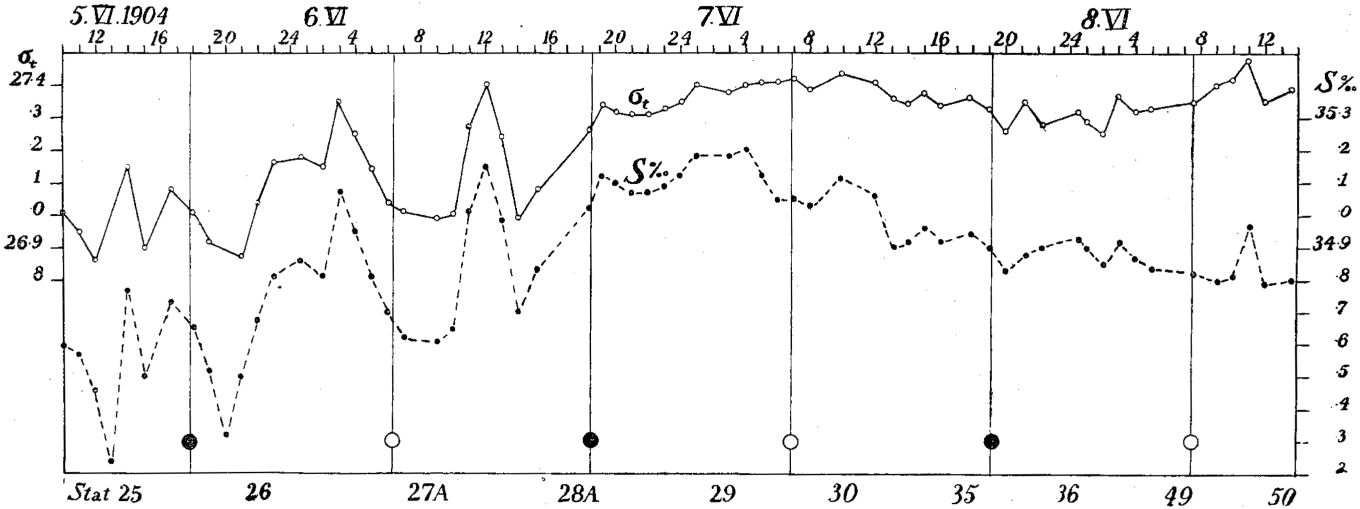

Fig. 21. Curves of Surface-Salinity ($S\,°/_{00}$) and Density (σ_t), June 5th—8th, 1904. Sea off Helgeland.

there are as a rule two maxima and two minima for each culmination (upper and lower), and the average period of the oscillations is consequently about $6^1/_4$ hours. Although it may be difficult to understand how these periodical oscillations are created, their regularity in the curves, and their coincidence with the upper and lower culminations of the moon are so marked that they can hardly be ignored as being merely accidental.

The curves of surface-density (σ_t) and surface-salinity (S ⁰/₀₀) in Fig. 20 (August 10th to 12th, 1903) and Fig. 21 (June 5th to 8th, 1904) exhibit more or less similar oscillations; but their periods are less regular, and their coincidence with the culminations of the moon less perfect. The observations of Fig. 20 were taken along the route between Norway and Iceland across the southern part of the Norwegian Sea, near its southern boundary (cf. Pl. X & XXI A, Fig. 1). In these curves the culminations of the moon appear to coincide with minima of the curves, this being especially the case in the sea north of the Færoe-Iceland Ridge, in the latter half of the curves. In this region there are surface-waters with high salinities to the south, and with lower salinities to the north. The observations of Fig. 21 were taken in the sea off Helgeland along the route of the *Michael Sars*, south-westwards from the Vestfjord (cf. Pl. XII, and Pl. XXIV A, Fig. 3). In the latter half of the curves especially (in the central part of the southern Norwegian Sea (cf. Pl. XII)), the culminations of the moon appear to coincide with minima of the curves.

The curves of surface-salinity and surface-density in Fig. 22 represent observations from March 3rd—6th, 1901, taken in the sea between Norway and Bear Island (cf. Pl. IV Fig. 1, Stats. 18—28; and Pl. XV Figs. 4 & 3). The first part of the curves, during the north-westward voyage of the ship, exhibit no distinct periods in their variations; but after March 4th, 10 a. m., they show a very distinct period of five hours(1), with only one irregularity on March 5th, 2—4 p. m. (15—16). At that time the ship was approaching the boundary of the coast-water (cf. Pl. IV, Fig. 2), and a part of it may have been carried seawards, *e. g.* by a cyclonic vortex-movement. It is a strange coincidence that just on March 4th, 11 a. m., the ship's course was turned southwards to Stat. 25, then westwards to Stat. 26, and then south-east towards the Sörö in Norway (cf. Pl. IV, Fig. 1). On March 4th, 6 a. m., the ship was amongst ice-floes at the edge of the pack-ice, south of Bear Island, which explains the very low salinity.

The observations from the deeper strata at Stations 18—28, are taken at far too great intervals to give any periods. The vertical sections (Pl. XV, Figs. 3 & 4) demonstrate that the density was very uniformly distributed vertically, there being, for instance, very little difference between the densities (or between the temperatures and salinities) at 100 metres, 50 metres, and 0 metres at the same station. The varia-

(1) It is a strange coincidence that if we assume that there is a stationary wave in the Norwegian Sea, and we compute the period of this wave by means of MERIAN'S formula $\left(t = \frac{2\,l}{\sqrt{2\,g\,p}}\right.$, where t is the period of oscillation in seconds, l the length of the sea-basin in metres, p its average depth in metres, and g the acceleration of gravity), we find the period to be about 5 hours and a half, supposing the length of the basin to be 16 degrees of Latitude, and its average depth 1600 metres.

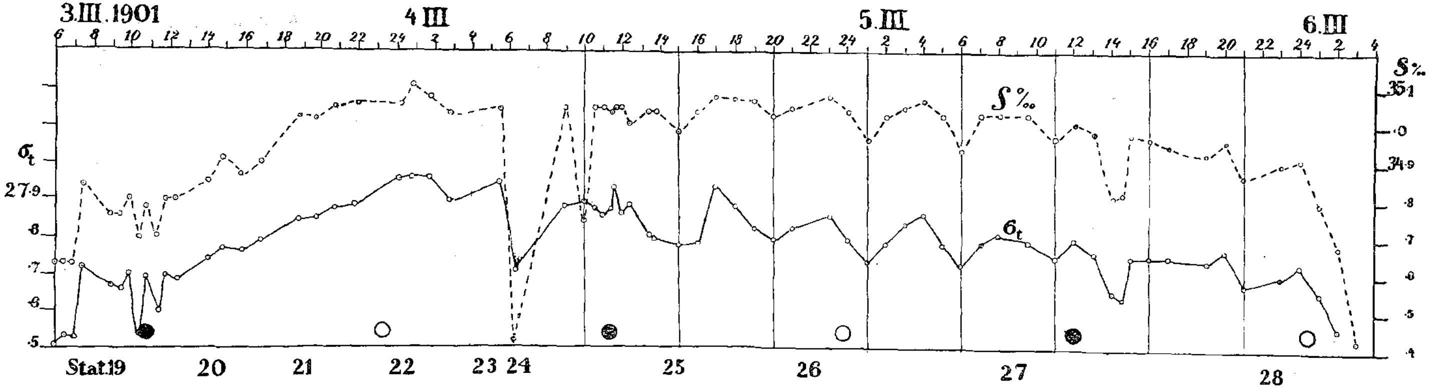

Fig. 22. Curves of Surface-Salinity ($S\,^0/_{00}$) and Density (σt). March 3rd—6th, 1901. Sea between Norway and Bear Island.

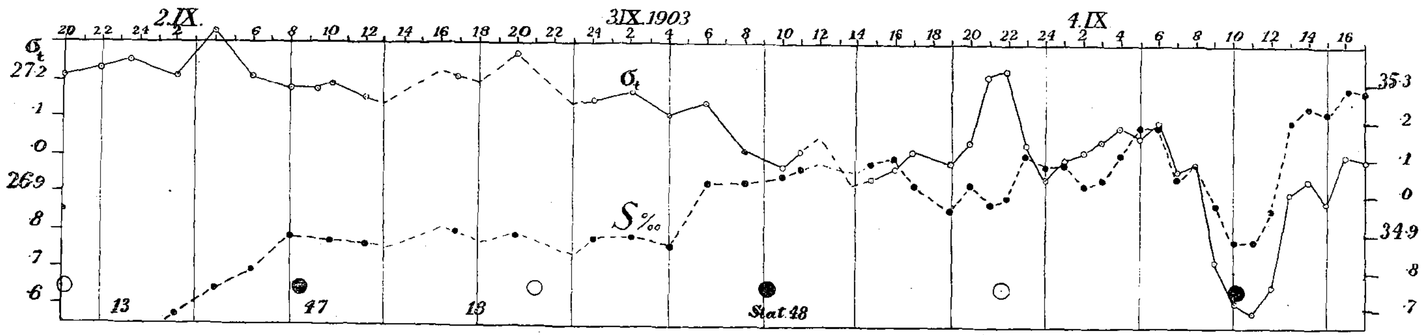

Fig. 23. Curves of Surface-Salinity ($S\,^0/_{00}$) and Density (σt), September 2nd—4th, 1903. Sea east of Iceland.

tions cannot therefore be explained simply by vertical oscillatory movements of the upper water-layers unless it be assumed that there has been a very thin surface-layer with comparatively low salinity, which only at certain intervals of time was accumulated to greater thickness so as to become an appreciable part of the surface-samples taken. This possibility was, however, excluded in this case, as the weather was very stormy, and the surface-layers had been well stirred.

If the remarkably regular variations have really been due to oscillatory movements of the water, som kind of lateral oscillatory transportation of the surface-water might be more readily imagined, although it is extremely difficult to understand how such movements could be sufficiently rapid to produce much difference in the water in the short space of 2 hours and a half, from minimum to maximum. The ship would naturally also be carried along by these movements; but if they were not simultaneous over the whole area, it might still be possible for the ship to be carried in one direction, while the water in front of her had just been carried in the opposite direction. A further difficulty is that the water of the minima, between Stat. 25 and Stat. 27, has a lower salinity (34·97—34·94 ‰) than is observed at any depth in this part of the sea (cf. Pl. XV Fig. 3, and also Fig. 4; see also Pl. IV), and it seems difficult to explain where this water has so suddenly come from at each minimum. It is worthy of note that the greatest variations and the lowest minima (the regions of coast-water and ice-water excepted) occurred during the homeward voyage between Stat. 25 and Stat. 28 (1), when the ship was farther west than on the northward voyage, between Stats. 20 and 24 (cf. Pl. IV). The explanation may be that there is probably very often a cyclonic vortex-movement in this sea between Bear Island and Norway, and the vessel may have been near the central part of this vortex, where there is often surface-water with low salinity as it has been intermixed with Arctic water coming from the north, from the sea near Bear Island [cf. NANSEN, 1906, Pl. I]. This water with lower salinity may have been scattered over the sea-surface at certain intervals by small vortex-movements or in some other way. But there is no regularity to be discovered in the distances between the places where the minima occurred, as they differ much.

But whatever their causes may have been, the variations demonstrated by our curves in Fig. 20 appears to have too much regularity to be quite easily explained as merely accidental.

It ought perhaps also to be mentioned that spring-tide occurred just during the homeward voyage, between Stat. 27 and Stat. 28. There was new moon on March 5th, 8 p. m. (20), 1901.

Fig. 23 is an example of another curve of surface-densities, which shows remarkably regular periods of 5 hours. These observations were taken between September 1st, 8 p. m., and September 4th, 5 p. m., 1993, in the sea east of Iceland, between Stat. 46 and Stat. 48 and south-east of the latter station (see Pl. X, Figs. 1 & 2, and section Pl. XXII, Fig. 7). As shown by the surface map, Pl. X, the ship, when sailing south-eastwards from Stat. 18, was in a boundary region, where a lateral movement of the surface-water towards the north-east or towards the south-west may lower the surface-temperature and raise the density or *vice versa*. Fig. 23

(1) The weather was then more windy than during the northward voyage.

shows that the variations in the density are chiefly due to variations of temperature, because the variations in the salinity are very often in the opposite direction. A striking fact shown by the curve of surface-density is the conspicuous maxima which occur near the upper culminations of the moon while near the lower culminations there are more or less pronounced minima. This might prove that there are at least two different periods which coincide near the upper culminations of the moon, when the effects of the periods accumulate; but here again the observation-material is much too incomplete to give any trustworthy information on this point.

It will thus be seen that the observation-material at our disposal is not sufficient to allow of our drawing any certain conclusions with regard to the possible oscillations mentioned, especially as the observations were not collected with the view of studying this difficult problem. Systematic and continuous investigations carried on at the same place for a long time would be requisite for this purpose. All we can say at present is that many of our observations indicate the probability that *great, hitherto unknown, oscillatory movements may occur in the intermediate strata of the sea, and also at its surface.* These movements may be *waves* of some kind, on the boundary between water-strata with different densities. Boundary waves generally occur singly, but periodical oscillations may be produced by a series of such waves, if the impulse creating them be regularly repeated at certain intervals of time. We consider it probable, for instance, that the tidal waves passing into a basin across a suboceanic ridge, like that between Scotland and Greenland may give regular impulses such as these. It is even possible that the tidal waves may thus to some extent be transformed into boundary waves, which will advance with much reduced velocities.

Oscillatory movements, like those mentioned, may possibly also to some extent be due to some kind of *pulsation in the velocity of the sea-currents*. Both kinds of movements may possibly cause periodical movements and consequent variations in the surface-water(1).

(1) It is very difficult to explain how appreciable variations in salinity, temperature, and density, may thus arise. If we assume that some horizontal, or lateral, oscillatory transportation of the surface-water is caused, which is probable, it is difficult to understand how this can produce any great variation because the velocities cannot be so great that the oscillatory movements can carry the surface-water any great distance in the few hours of half the periods. It might be more reasonable to suppose that an increased movement of the surface-strata, will stretch the strata so to speak, and consequently diminish their thickness, while a decrease or stop in

If the variations observed be caused by two or several oscillatory movements with different periods, the resulting period of the variations observed may, of course, be very irregular and complex.

c. "*Pulsations*" *in Sea-Currents.*

If such "waves" or "pulsations" really occur in the sea, they may be investigated by current-measurements. The only direct measurements that have been made of currents in the Norwegian Sea are those which Helland-Hansen made during a cruise with the *Michael Sars* in July, 1906, and which he has described in his paper of 1907.

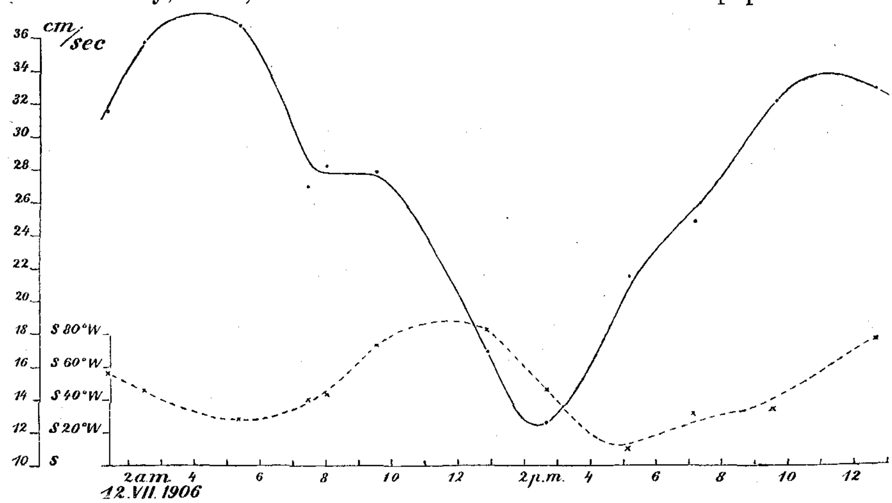

Fig. 24. Curves of Velocity (unbroken line) and Direction (broken line) of Current at 10 Metres. Stat. 307, Storeggen, July 12th, 1906.

He had two stations off the Norwegian Coast, in 62° 32′ N. Lat., 5° 25′ E. Long. (Stat. 299), and in 62° 50′ N. Lat., 4° 47′ E. Long. (Stat. 307). The former Station was on the "Skreigrund" off Aalesund, where the depth to the bottom was 70 metres; and here the measurements proved that there were varying ordinary sea-currents as well as tidal currents. It is difficult, however, to find any definite periods in the variations of the ordinary current at this place. Station 307 was on the edge of the Continental Slope (Storeggen) off Aalesund, the

the movement may make the surface-strata considerably thicker; and if there is much difference between the strata near the surface, a bucket may in the former case take more water from the underlying strata than in the latter. But even this explanation does not appear to be very satisfactory.

depth being 260 metres. In order to study possible waves of the kind mentioned above, we have examined the current-measurements from this station very closely and have obtained some results which seem to prove the existence of such "waves".

The measurements at Stat. 307 were made continuously for more than 24 hours, on the 12th and 13th of July. The observations at a depth of 10 metres below the surface are represented in Fig. 24, the

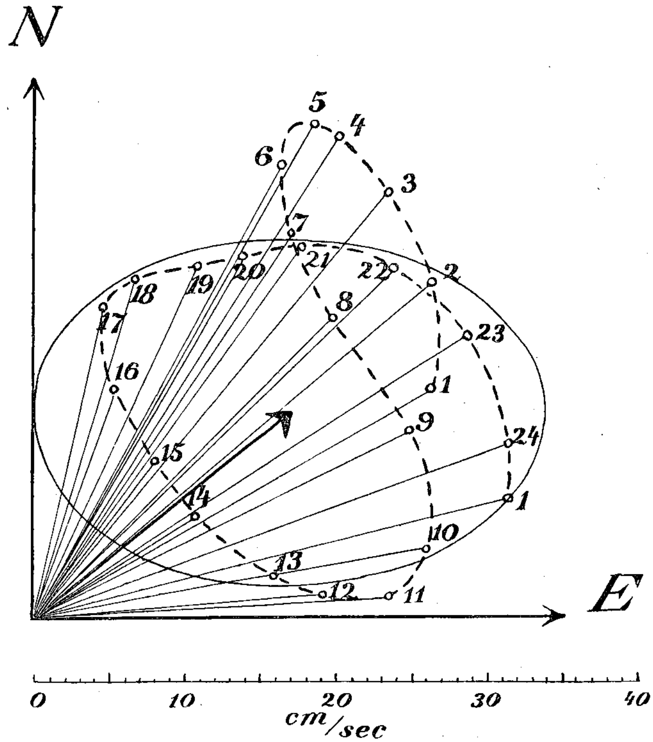

Fig. 25. Central Vector Diagram. Storeggen, 10 Metres.

unbroken line being the curve for the velocity (in centimetres per second), and the broken line that for the direction. By means of these curves we have found the velocity and direction of the current for each hour, the values thus found being shown by a central vector diagram in Fig. 25, where they are connected by the broken line(1).

The shape of the broken-lined curve in Fig. 25 proves the existence of complex movements, and may be explained by the assump-

(1) In Figs. 25, 26, 27 and 29 the hours from midnight to midnight have been reckoned as 0 to 24.

tion that the current was composed of a tidal current and a varying ordinary sea-current. If the tidal influence could be eliminated, we should find the sea-current itself and be able to study its variations.

The tidal wave proceeds northwards through the Norwegian Sea. Near the coast, or wherever the bottom rises towards the surface, the wave will be retarded; and at Stat. 307 it must therefore run obliquely towards the coast-line. It is thus very probable that the tidal wave at this place moves from west to east, causing at flood-tide the water to run in this direction towards the coast, and at low-tide in the opposite direction, seawards. On account of the variations in the velocity of the tidal current, the line of its advance will be elliptical in form [cf. v. ROOSENDAAL and WIND, 1905, and HELLAND-HANSEN, 1907, a]. If the tidal current for each hour be represented by a central vector diagram, the major axis of the ellipse will have the same direction as the tidal wave itself, *i. e.* in our case from west to east. The direction of the current will vary, cyclonically if the nearest land is to the right, and anticyclonically if the nearest land is to the left [cf. KRÜMMEL, 1887, and the Introduction to the British Tide-Table]. The variation at the station in question was in all probability cyclonic.

In Fig. 25 we have introduced an ellipse with the major axis along the west-east line. We have made a good many attempts to determine the most probable situation of this ellipse in the figure, and find this to be the situation which agrees best with the observations. Owing to our lack of knowledge concerning the tidal wave and current in the Norwegian Sea, it is at present impossible to deal with this matter exactly.

The ordinary current runs parallel to the coast (or the edge of the continental slope), at our station in a direction about N 50° E Supposing that this current were constant in direction and velocity, we should find that all the points, representing the observed velocities and directions, one for each hour, would be grouped along the ellipse, and not along the broken line that the observations gave. The position of these points along the irregular curve may easily be explained, however, by assuming that the sea-current had an almost constant direction (towards N 50° E) but varying velocities. On account of these variations the point would be moved from the ellipse to the other curve, this displacement being easily found by projection of the points from one curve to the other along the main direction (N 50° E). The displacement will be positive or negative when reckoned along this direction; and the total velocity of the ordinary sea-current after the elimination of the tidal current will be found by adding (with

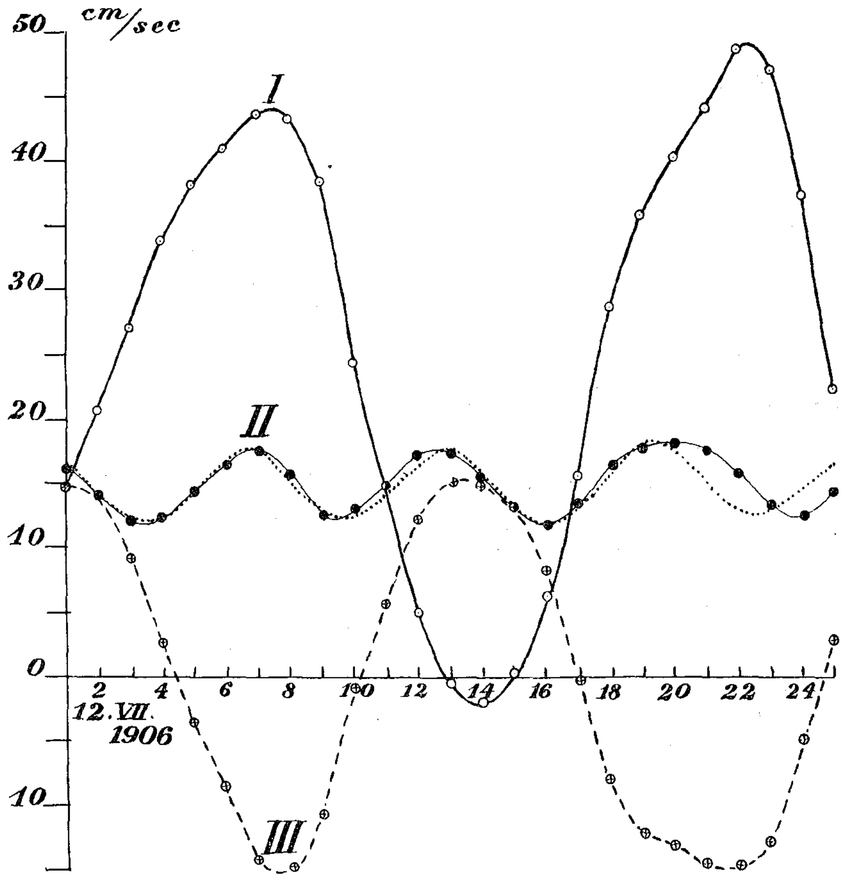

Fig. 26. Curves of Velocity.

plus or minus) the displacement to the distance from the origo to the centre of the ellipse.

Curve "I" in Fig. 26 is found in this way. It represents the ordinary sea-current, after the tidal current has been eliminated in the manner just mentioned, by means of the curves in Fig. 25. We have assumed, then, that the direction of the ordinary sea-current was quite constant. This curve "I" in Fig. 26, shows a well-defined periodicity, with a period of about 15 hours. The velocity, as found by this curve, is about nought at minimum, and at maximum almost 50 centimetres per second. These variations are much larger than those caused by the tides.

The unbroken line, "II", in Fig. 26 represents the velocity of the tidal current when the directions are ignored. The theoretical curve, typical for tidal currents, is drawn as a dotted line along the former [cf. Helland-Hansen, 1907, pp. 16—18]. The unbroken line ("II") is found in the following way. The points along the irregular curve in Fig. 25 have been projected along the direction N 50° E—S 50° W, on to the ellipse. The distance from the centre of the ellipse to the projected points found in this way, have been plotted out in Fig. 26, and form the curve "II" in question. It is quite remarkable how well this curve agrees with the theoretical one, only the last part of it—to the right—being a little different in form. This almost complete agreement between the two lines, marked II, is a strong indication of the correctness of our mode of procedure. No such agreement would have been found by means of the theoretical ellipse (Fig. 25) if the observations had given other values than they actually did.

Curve "III" in Fig. 26 represents the components of the tidal currents along the directien S 50° W—N 50° E, the north-eastward components being introduced above the abscissa and the south-westward components below it.

We have thus assumed that in 10 metres a tidal wave came in from west to east, and that the tidal currents at the station in question ran their ordinary elliptical course in a cyclonic direction, the position of the major axis of the ellipse being thereby determined. The size of the ellipse is taken from the observations, as best suits, and should give a maximum of the current of 17—18 $\frac{\text{cm.}}{\text{sec.}}$, and a minimum of about 12 $\frac{\text{cm.}}{\text{sec}}$, values that appear to answer well to the probable conditions. From the position of the projected points on the ellipse, which also determines the velocity-curve II, the observations can be simply explained by assuming that there have been pulsations in the ordinary current, with periods of about 15 hours. Curve I, which applies only to the ordinary current, seems to represent as nearly as possible the actual circumstances; the magnitude of the variations may of course have been a little different, but the periods are probably correct. It is impossible to express any decided opinion as to how these pulsations are to be regarded; but they appear to correspond to the waves we have mentioned above, and are due either to a wave in the current, or to something that might be likened to the stroke of a pump.

Under these circumstances then, the current will be composed of an ordinary sea-current and a tidal current, both with decided periodical variations. As the periods are different for the two kinds of currents, the resultant motion will show periods of various lengths and various amplitudes. In Fig. 27, the entire line indicates the

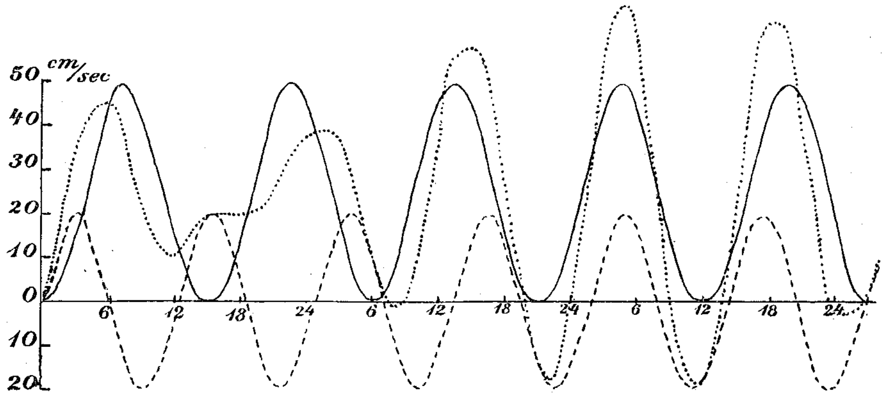

Fig. 27. Theoretical Curves of Velocity. Unbroken line the Ordinary Sea Current; broken line the Tidal Current; dotted line the Resulting Current.

velocity of the ordinary sea-current. The period is put at 15 hours, as we found it above, and the oscillations at from 0 to 50 $\frac{\text{cm.}}{\text{sec.}}$, as nearly as possible answering to the conditions represented in Fig. 26. The broken line shows the velocity component for the tidal current in the direction of the ordinary sea-current: the maximum velocity is assumed to be 20 $\frac{\text{cm.}}{\text{sec.}}$. The resultants of these motions in the direction of the main current is shown by the dotted line. It shows periods of various lenghts from 12 to 20 hours. The oscillations also vary, the smallest maximum being nearly 40 $\frac{\text{cm.}}{\text{sec.}}$, and the greatest nearly 70 $\frac{\text{cm.}}{\text{sec.}}$. In the course of about 72 hours, the original conditions have returned once more. Sometimes, for from 4 to 6 hours, the current will flow in a direction the reverse of the average, a circumstance which may explain why certain currents sometimes exhibit motions the reverse of the ordinary, as is frequently observed by the fishermen off the coast of Norway.

In the deeper strata at the current-measurement station out on Storeggen, the conditions were more composite. Fig. 28 shows the velocity and direction at a depth of 100 metres. The direction-curve shows a decided period (of 7 hours). The velocity-curve falls the whole time from a maximum at the beginning of the measurings. The central vector diagram in Fig. 29 corresponds with that in Fig. 25. In this case it is not possible to explain the observations by a single tidal movement and a pulsation in the ordinary sea-current. We have

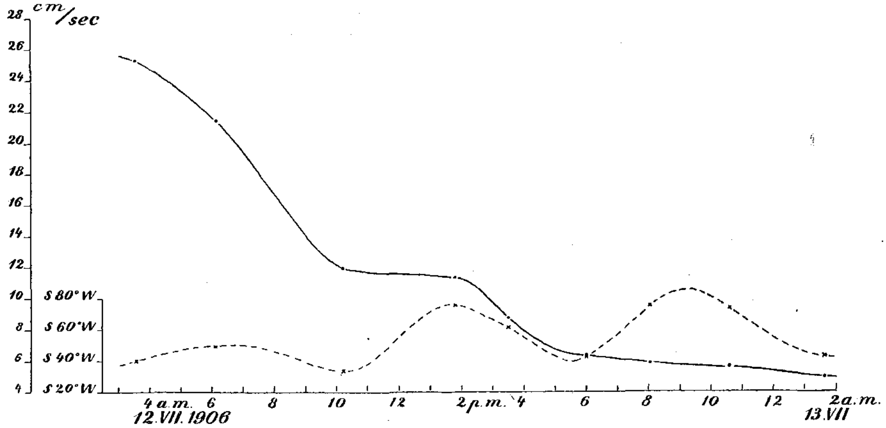

Fig. 28. Curves of Velocity and Direction (broken line) of Current at 100 Metres. Storeggen, July 12th, 1906.

endeavoured to construct various ellipses similar to that in the former case; but the position of the points on the broken line show it to be impossible that there has been a displacement backwards and forwards in only one direction. If we presuppose a certain movement with the tidal current, and eliminate it, there will still be a composite motion left. The curves of direction that can be constructed after such an elimination of the primary tidal wave, indicate that there is still another motion of the nature of the tidal currents, probably a reflected tidal wave. It is scarcely worth while trying to eliminate this, as the uncertainty will be far too great, and there will be too much room for hypotheses. It would require the taking of observations through a considerably longer period than 24 hours to throw light upon these conditions.

From the open sea, with sufficient depths, there are no reliable current-measurements but those mentioned here. We have therefore not yet sufficient observation-material for a more thorough investiga-

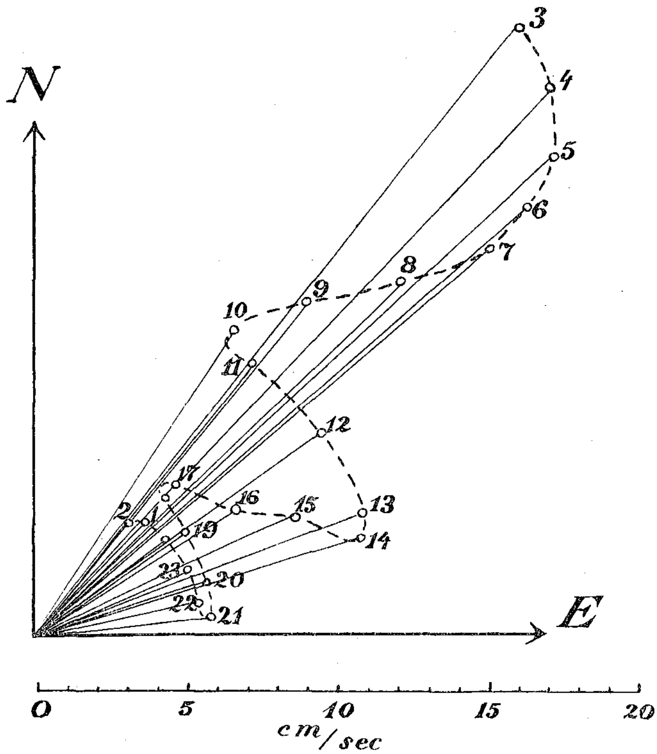

Fig. 29. Central Vector Diagram. Storeggen, 100 Metres.

tion of these conditions; but we think, that even the facts here mentioned seem clearly to indicate the existence in the Norwegian Sea of hitherto unknown waves that have a period of many hours, and which reveal themselves in the ordinary hydrographic sections.

d. Periodic Variations in the Hydrostatic Equilibrium.

Periodical variations in the velocities and directions of the currents, of the kind mentioned above (Pulsations as well as the Tidal Currents), must cause periodical variations in the levels of the water-strata. These variations may probably be considerable along the continental slopes on the right side of the current. Let us suppose, for instance, that the surface-velocities of the Atlantic Current along the edge of the Norwegian continental shelf be *increased.* Owing to the effect of the Earth's rotation the relatively light surface-strata will then be pressed down to lower levels along the continental slope on the right side of the current, and they will approach a new level of equilibrium conditioned by the increase in the surface velocity.

A *decrease* of the surface-velocities, or an increase of the velocities of the underlying strata, will have the opposite effect.

Variations in the *direction* of the currents will naturally also cause changes in the levels of the strata, depending whether the current be turned towards the continental slope, or more seawards.

We have seen above that such variations in the Currents actually occur even periodically, and they are of two kinds, at least (pulsations, and tidal variations). We must consequently conclude that vertical oscillations in the level of the strata are thus created. The magnitude of these oscillations will naturally depend upon the amplitude of the vatiations in velocity and direction, and upon their duration; for the strata will require some time to reach the level of equilibrium conditioned by the changes in velocity.

We have seen above that the variations in the velocities of the current may be very great; it is therefore probable that the vertical oscillations of the strata, caused by them, are considerable.

e. Temporary Disturbances of the Hydrostatic Equilibrium.

It is clear that any sudden, local change in the horizontal movements of the surface-layers of the sea will cause changes in levels of the underlying heavier water-strata, which may be either depressed or raised at the place where the sudden change in the surface-movements occurs. In a section which happens to pass through a region of the sea disturbed in this manner, the depressed or raised underlying strata may have the appearance of waves. Let us suppose, for instance, that a sudden strong, local wind creates a local surface-current, or a local acceleration or retardation of the surface-current, or a change in its direction, at a certain place. It is clear that the underlying heavier water-strata must then be raised at this place and be depressed in front of the wind. A wave is consequently formed, which remains more or less permanent for some time, if the wind continues unaltered. An experiment demonstrating this process can easily be made in a laboratory. Fig. 30 illustrates an experiment of this kind made by J. W. SANDSTRÖM [1908, p. 10]. He had in a vessel a lighter water-layer resting on the top of a heavier layer, with a sharply defined boundary, one of the layers, being coloured for the purpose of distinction. By letting a strong, narrow air-current suddenly act locally, at a certain place on the surface of the light water-layer, this layer was put in motion in the direction of the air-current, and the underlying heavier water at this place and behind it, was lifted to form a very great wave, while in front of it the heavier water-layer was depressed. If the air-current continues to act on the surface at the same spot for some time, the wave in the underlying heavier water will remain permanently, altering its shape gradually until a new condition of stable equilibrium is attained, If the spot at which the air-current acts on the water-surface moves forward (in the direction of the air-current), the wave will follow in the same direction. If the air current suddenly stops, the wave will continue its course as a boundary-wave, with the velocity of an ordinary boundary-wave, until it reaches the wall of the vessel, or if we think of the sea, until it reaches the side-slope of the sea-basin. Here it will partly be broken and partly be reflected, and will again pass across the basin, till it reaches the other side. Any sudden storm or wind on the sea, may have an effect upon the water-strata, similar to that demonstrated by such experiments, and thus subsurface-waves or boundary-waves may easily be created; and it makes no essential difference in this respect whether the water-strata were at rest, or were being carried along by a permanent sea-current before the sudden wind or storm began to act. By a succession of several storms in a basin like that of the Norwegian Sea, much disturbance may be produced in this manner in the different water-strata underlying the lighter surface-layer, and many different boundary-

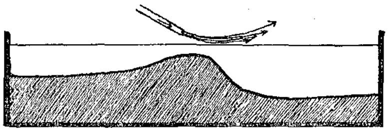

Fig. 30. Boundary-wave formed by local Air-Current [cf. SANDSTRÖM, 1908, p. 10].

waves may be created. The possibility will thus exist that in a very stormy season several boundary-waves will move in different directions at the same time, and will cause very complex and apparantly irregular oscillatory movements of the intermediate strata. They may also unite to form stationary boundary-waves, which may possibly last for some time.

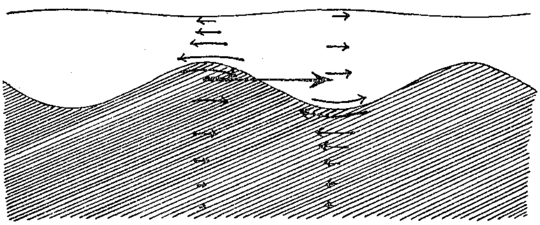

Fig. 31. Boundary-Waves [cf. V. W. EKMAN, Pl. VI, Fig. 4].

Fig. 31 is a reproduction of a figure by Dr. V. W. EKMAN [1906, Pl. VI, Fig. 4] representing waves on the boundary between a layer of fresh water resting on heavier sea-water. The boundary-waves are advancing from left to right as indicated by the long arrow. The small arrows indicate the velocities and directions of the orbital movements of the water-particles. The height of the surface-waves is exaggerated 30 times, in order to make the waves visible in the drawing.

The boundary waves in the sea move very slowly; their velocity depends upon the difference of density between the two water-strata, and increases with the square root of this difference. The velocity with which a boundary-wave advances is, according to HELMHOLTZ's formula,

$$V = \sqrt{\frac{\triangle q}{q} \times \frac{g}{\frac{1}{d} + \frac{1}{D}}} \quad \frac{\text{m.}}{\text{sec.}}$$

where $\triangle q$ is the difference of density between the upper and the lower stratum, q the density of the upper stratum, d the thickness (in metres) of the upper stratum, and D the thickness of the lower stratum.

Supposing the values to be: $\triangle q = 0{\cdot}0005$, $q = 1{\cdot}02750$, $g = 9{\cdot}8$, $d = 100$, D 2000, we find that $v = 0{\cdot}68 \frac{\text{m.}}{\text{sec.}} = 1^1/_3$ knot $= 32$ nautical miles in 24 hours. During half a tidal period ($6^1/_4$ hours) the boundary wave would consequently advance only 8·3 miles, and in a whole tidal period ($12^1/_2$ hours) 16·6 miles.

The boundary-waves will create waves on the surface with the same wave-length, but a much smaller height. If the wave-length be very great as compared with the thickness of the surface-layer, the ratio between the height of the surface wave (h) and that of the boundary wave (H) may be assumed as

$$\frac{h}{H} = \frac{\triangle q}{q}$$

This will be $\frac{0 \cdot 0005}{1 \cdot 0275} = \frac{1}{2055}$, if the same densities as above be introduced. Upon this supposition the boundary-wave will be 2055 times as high as the surface-waves. If the latter be 5 cm. the boundary wave will not be less than 100 metres high. It should also be noted that the surface-wave will have a crest where the boundary wave has a trough, and *vice versa.* The velocities of the movements of the water-particles on the surface will be considerably less than the velocity with which the wave advances, and are proportional to the heights of the waves.

But sudden local changes in the velocity of the current may not only create boundary-waves in the underlying water-strata, but may also result in local horizontal vortex-movements, with vertical axis. If, for instance, the velocities on the right side of a current be suddenly much increased—*e. g.* by a local wind, or by being pressed up against the side slope of the sea-basin,—whilst the velocity of the water on the left side of the current remains unaltered or is even retarded, a cyclonic vortex-movement may then suddenly be formed locally. If the retarded water be on the right side of the accelerated part of the current, the vortex-movement thus arising will be anticyclonic.

f. Cyclonic (or Anticyclonic) Vortex-movements.

Our numerous observations from the various years make it probable that at least some of the great bends or "waves" of the equilines in our sections are due to horizontal cyclonic vortex-movements. Let us first examine the four sections seawards from Lofoten, for May

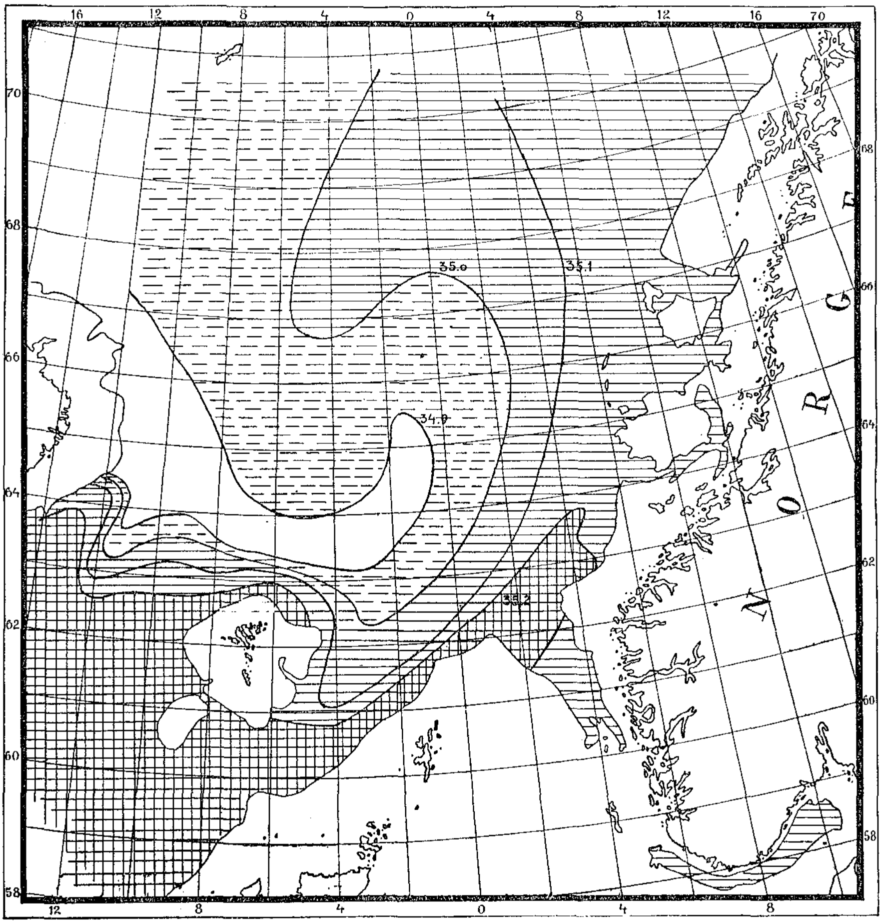

Fig. 32. Average Horizontal Distribution of Salinity at 300 metres, resulting from all observations taken during the years 1900—1904.

1901, 1902, 1903, and 1904 (Pl. XVI, Fig. 3; Pl. XVII, Fig. 2; Pl. XXI A, Fig. 4; Pl. XXIV A, Fig. 4).

Fig. 32 represents the average horizontal distribution of salinity at 300 metres, according to all our observations from the different years. The shape of the isohaline of 35·0 ‰ (and also that of 34·9 ‰) demonstrates clearly that there is a great cyclonic movement of the waters in this region of the sea. The great tongue which the isohaline of 35·0 ‰ forms west and south-westwards to about 67° N. Lat. and 5° W. Long., indicates that the water of 35·0 ‰ is there flowing in that direction, and this also explains clearly how it is that the Atlantic water with salinities above 35·0 ‰ has such a much greater westward extention in all our sections seawards from Lofoten, than in any section farther south.

Let us, for instance, compare the sections seawards from Stad (which run more transversely across the Atlantic Current than the Helgeland sections) with the sections seawards from Lofoten, in May & June, 1903 and 1904 (Pls. XXI A and XXIV A, Fig. 2, and Fig. 4). There is a striking difference between them in both years. The Atlantic water with salinity above 35·0 ‰ and temperature above 4° C. and 2° C. has a much wider westward extension in the northern sections than in the Stad sections. This is also very clearly seen in the salinity and temperature charts for 200, 300, and 400 metres (Pls. IX, XII) and also in the surface chart for May & June 1904 (Pl. XII). It is evident that the Atlantic water along the region of the Lofoten sections must to some extent be moving westwards in the direction of the sections; but probably this westward movement does not follow regular curves. As they proceed, the waters will certainly change their course irregularly, and will easily form whirlpools or vortices, just as the water of a great, quietly-flowing river will suddenly, and apparently quite irregularly, form great whirlpools wherever the river-bed makes a bend. Thus some, at least, of the "waves" or bends, up or down, of the equilines of our Lofoten sections are evidently due to the fact that the sections pass through volumes of Atlantic water flowing in different directions, owing to the cyclonic movement of the water.

We may take as an example the Lofoten section of May 1901 (Pl. XVI, Fig. 3). The great volume of Atlantic water, with salinities above 35·0 ‰, at Stats. 16 and 17, evidently belongs to the western part of the great cyclonic movement and has been moving in a westerly and south-westerly direction. At Stat. 18, the isohaline of 35·0 ‰ is lifted above the level of 200 metres below the sea-surface, while it is at 300 metres at Stat. 17, and at 400 at Stat. 16. At the next station on the other side, Stat. 19, it again falls abruptly to 400 metres. The apparent "wave" thus formed in the section at Stat. 18, is evidently due to the fact that this station was nearer the central part of the great cyclonic vortex, where, at depths between 200 and 400 metres, water with a lower salinity comes in from the south and west.

In the Lofoten section of May, 1902 (Pl. XVII, Fig. 2), the isohaline of 35·0 ‰ forms a similar "wave", and the conditions have evidently been much the same as in May, 1901. In the Lofoten section of May, 1903 (Pl. XXI A, Fig. 4), there is also a similar wave; but it is much farther east, and the water with salinities above 35·0 ‰ has not such a wide westerly extension as in the sections of the two previ-

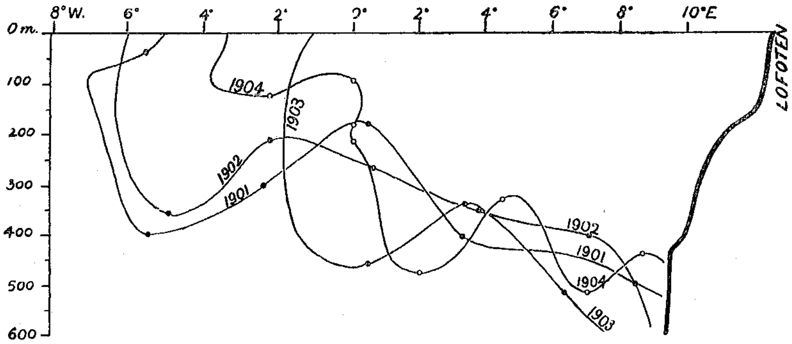

Fig. 33. Isohaline of 35·0 $^0/_{00}$ in the Section seawards from Lofoten, May, 1901, 1902, 1903, and 1904.

ous springs(1). It is, however, evident that the "wave" is due to the same cyclonic vortex-movements, which has had a somewhat different course that year(2).

The Lofoten section of May, 1904 (Pl. XXIVA, Fig. 4), differs somewhat [from the same sections of the previous years. There are more stations and shorter distances between them. The result is that more details are seen, and the equilines show more "waves" (se Fig. 33). "Waves" as numerous might also have been seen in the sections of the previous years if it had not been for the much greater distances between the stations. We consider it probable that the "wave" formed at Stat. 20 A and Stat. 19 A by the isohaline of 35·0 $^0/_{00}$ as well as by the isotherms of 2° and 4° C. (Pl. XXIVA, Fig. 4) is a formation similar to that seen in the sections of 1901 and 1902, at Stat. 18 in 1901, and at Stat. 19 in 1902. We must consequently assume that the water with a salinity above 35·0 $^0/_{00}$ (and with a temperature above 4° C. or even above 2° C, west of Stat. 20 A and Stat. 19 A, in 1904 was moving in a south-westerly direction (see Pl. XII, map for 50 metres), and was on the western side of the great cyclonic vortex of the southern Norwegian Sea, while Stat. 20 A and Stat. 19 A were nearer the axis of this vortex.

But at Stat. 21 A and Stat. 23 A, May, 1904, there are quite similar "waves" marked by all the equilines. At Stat. 20 B especially, all the curves descend to comparatively great depths, *e. g.* the isohaline of 35·0 $^0/_{00}$ and the isotherm of 4° C. descend below 440 metres, and the isohaline of 35·1 $^0/_{00}$ below 300 metres, and so on. The isotherm of 2° C. descends even below 700 metres (cf. Pl. XXIV A, Fig. 4). This volume of deep Atlantic water is altogether similar to that found at Stat. 20 in

(1) It is a strange fact, however, that no such difference between the four years 1901—1904, is seen in the westerly distribution of water with temperatures between 2° and 4° C. The isotherm of 2° C. has very nearly the same extension westwards in each of the four years, and the isotherm of 4° C. has also very similar shapes in these years. The isotherm of 6° C. shows greater differences, but the cause may be that the sections of 1903 and 1904, were taken about a fortnight later in the season than those of 1901 and 1902.

(2) The difference between that year and the two previous years cannot be explained by the fact that the situation of the section is slightly more southerly (see Pl. II), as that should if anything have had the opposite effect.

May, 1903 (Pl. XXI A, Fig. 4), but it is situated somewhat farther east in May 1904 (cf. Fig. 33). We consider it probable that it is formed in a similar manner, *i. e.* that it is water from the northward-flowing Atlantic Current, which has been carried by a vortex movement west- and south-westwards, as is clearly indicated by the charts for 300 and 400 metres (Pl. XII), and also by the shapes of the isopyknals in Pl. XXIVA, Fig. 4. This vortex, however, is a smaller and more local one, than the great cyclonic vortex-movement of the upper strata.

At Stat. 23 A, May, 1904, there is also a "wave" in all the equilines (except the isohaline of 35·1 ‰). This "wave" is quite similar in appearance to the two others at Stat. 21 A and Stat. 19 A, although somewhat smaller; and it might have a similar origin, *i. e.* a small vortex-movement has carried the Atlantic water in a south-westerly direction at Stat. 22, and has depressed the equilines at that station. But other explanations are also possible, *e. g.* a local wind near Stat. 23 A, or some other cause, might have created a lokal surface-current in that region. which has lifted the underlying water-strata. The regular vertical distribution of temperature and salinity between 0 and 100 metres, and the horizontal course of the isopyknals of 27·50 and 27·60 at Stat. 23 A, however, do not make such an explanation probable. Another possibility is that we have had here a boundary wave which had lifted the water between 150 and 600 metres during the hour of observation.

Although there certainly is a possibility that some of these "waves", especially the last mentioned one, might be otherwise explained, we consider it most probable that the three great and distinct "waves" seen in the Lofoten section of May, 1904, are all of them formed in the same manner, *i. e.* by great or small vortex-movements, circulating horizontally with vertical axes. We consider it probable that these vortices are to some extent caused by the configuration of the coast and the sea-bottom. The great cyclonic vortex-movement of the southern Norwegian Sea (see Fig. 32) is probably created by the joint effect of the *East Iceland Arctic Current*, running south-eastwards east of Iceland and along the Færoe-Iceland Ridge, and the *Atlantic Current* running north-east and northwards along the coast of Norway. The latter current is to some extent impeded in its course by the Helgeland Ridge, since a current runs more freely where the sea is deep than where it is shallower. Some part of the Atlantic Current is therefore in that region deflected towards the west, and this circumstance helps to form the great cyclonic movements of the southern Norwegian Sea. Some water of the upper strata, between the surface and 200 metres (see Pl. XII, charts for 50, 100, and 200 m.), is also stopped in its northward course by the Lofoten Bank, and is driven westwards, to some extent with increased velocities (see

Fig 45). It is thus that the westward movement of the Atlantic water in this region may be started. Wherever the velocities of water are too much increased or too much retarded for one reason or another, horizontal vortices, inside the great cyclonic movement, may easily be formed in this region where the direction of the great Atlantic Current is already so much disturbed. Thus a vertical section may easily pass across several such vortices in this region, and exhibit great "waves" such as those seen in the section of May, 1904.

But these vortices or "waves" may vary much in their position and probably also in number. This is proved by Fig. 33, where the isohaline of 35·0 ‰ of the four Lofoten sections mentioned has been introduced in one section. It is seen that hardly any "wave" is in the same position in two different years. The isohaline of 35·1 ‰, also shows great variations, although not to the same extent. The number of stations differs in the various years; but the probability is that if there had been more stations we should also have seen more "waves", and the want of harmony between the different sections might have been still greater.

If we assume that the stations taken, for instance in May, 1904, have been sufficiently numerous to show, at any rate approximately, the correct shape of the equilines in the section in Pl. XXIV A, Fig. 4, the inclinations of the isopyknals prove that the water has been running with very different velocities, and in very different directions, between the various stations.

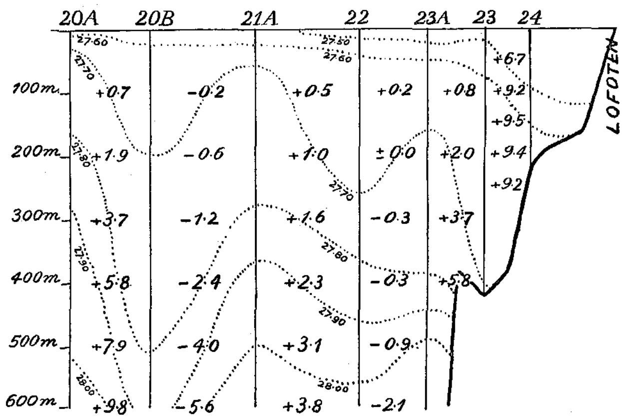

Fig. 34. Section seawards from Lofoten, May, 1904, giving the differences, in cm. per second, between the velocities at the surface and at the several depths down to 600 metres. The dotted lines are the isopyknals of 27·50—28·00.

In Fig. 34 we have introduced the difference in centimetres per second between the surface-velocities and those computed(1)

(1) According to BJERKNES's theory.

for the water at depths of from 100 to 600 metres between each two stations of this section (May, 1904). *Plus* in front of the figures means that the water between the two stations has been running northwards, *i. e.* in the main direction of the current, while *minus* indicates that the water (*i. e.* the component computed by us) has been running in the opposite direction, in relation to the waters on each side. These waters with minus velocity may either have been running southwards (*i. e.* the component computed by us has had a southward direction), as is most probable, or if we assume that the whole water-mass represented by the section has had a northward movement, the minus velocities indicate that the water between those stations has been retarded in its northward movement, and as much more at the surface than at the different depths as the figures indicate.

Fig. 34 proves that the water near the continental slope, between Stat. 23 A and Stat. 24, has been running northwards with comparatively great velocity, especially between Stat. 23 and Stat. 24, where for instance the difference between the surface-velocity and that at 225 metres was 9·2 cm. per second. Between Stats. 22 and 23 A, the water between the surface and 200 metres has probably been running very slowly northwards, but between 200 and 600 metres it has been running slowly in more or less the opposite direction, the difference in the velocity at the surface and at 600 metres being — 2·1 cm. per second, as computed along the component perpendicular to the plane of the section, *i. e.* the north-south component. Between Stats. 21 A and 22 the water has again had a northward movement, but not very rapid, the difference between the surface and 600 metres being only 3·8 cm. per second. But between Stats. 20 B and 21 A the water was moving rapidly in the opposite direction, especially between 400 metres and 600 metres, where the difference increased from — 2·4 to — 5·6 cm. per second. Between Stats. 20 A and 20 B the water was moving rapidly northwards, the difference in velocity between the surface and 600 metres being 9·8 cm. per second.

These computations are naturally based upon the supposition that the "waves" in the isopyknals of the section are not due to any kind of wave-action, but are caused by some kind of horizontal vortex-movements, or by local retardations in the current, which alter its velocities and directions.

This example may be sufficient to explain how very complicated the movements of the water seen in a section, may actually be.

If our view be correct, namely, that the great "waves" seen in our Lofoten sections, indicate cyclonic vortices in the water of the Atlantic Current, it is probable that similar vortices may be formed in this current farther south, and may also there appear as "waves" in the sections. In the two sections seawards from Helgeland, of May & June, 1903 and 1904 (Figs. 3, Pls. XXI A & XXIV A) there are no "waves" of this kind, a fact which may indicate that the current usually has a very straight course just in this region, as it meets with little resistance; but it is of course possible that if the distances between the stations had been shorter, some "waves" might have appeared in the sections.

The section seawards from Stad of June, 1903 (Pl. XXI A, Fig. 2), is very like the Helgeland sections in this respect, and exhibits no "waves"; but it is possible that if, for instance, there had been stations between Stats. 31, 32, and 33, the equilines might have had different shapes. In the section of November, 1903 (Pl. XXIII, Fig. 3), through almost the very same region, there are marked indications of "waves". In the section somewhat farther south, off Stad, of June, 1904 (Pl. XXIV A, Fig. 2), there is a very high "wave" by which the Atlantic water is divided into two masses, one smaller near the continental slope, and one greater mass on the seaward side of the wave. We consider it probable that in this case there has been a well developed cyclonic vortex-movement, which has carried the latter greater mass of Atlantic water seawards from the northward-flowing current which is pressed to the right against the continental slope and the edge of the continental shelf. Just southwest of this place, at the mouth of the Norwegian Channel, this shelf has a deep embayment, and a little beyond it, to the north-east, the continental edge begins to trend in a more northerly direction. The cyclonic vortex is seen very clearly in the dynamic charts for 100 and 200 metres (Figs. 45, 46) and also in the charts, Pl. XII, showing the horizontal distribution of salinity at 50, 200, 300, and 400 metres (see also the shape of the isotherms of 4° C., at 400 metres, and of 2° C., at 500 metres). But the isohalines of these charts might perhaps be drawn in a somewhat different manner as is demonstrated in Fig. 37. If, for instance, we look at the isohaline of 35·2 ‰ in the charts for 50 and 200 metres, we find a more rational explanation of the movements (agreeing better with the shape of the isohaline of 35·1 ‰ at 300 metres and 35·0 ‰ at 400 metres) if we give it shapes as in Fig. 37 instead of those in Pl. XII. It is proved, for instance, by the isotherm of 8° C., that the water of above 35·2 ‰ at 50 metres was carried to Stat. 70 (cf. Pl. XII) by a cyclonic movement as indicated in Fig. 37. If the horizontal distribution had been as drawn in Pl. XII, 50 metres, the isotherm of 8° C. would form a closed curve round Stat. 70 (cf. Pl. XII) which is improbable; while in Fig. 37 it is connected with the isotherm of 8° C. to the east (on both sides of Stat. 39, Pl. XII, see also Pl. XXIV A, Fig. 2) and south, which seems natural.

It thus appears probable that the great bulk of water with salinity above 35·2 ‰ between Stat. 37 and Station 70, in the section in Pl. XXIV A, Fig. 2, has been carried westwards by a cyclonic vortex-movement from the Atlantic Current running towards the north-east, along the continental slope, between Stat. 38 and Stat. 40. But it is a striking fact that at Stats. 37 and 70, there is a thick layer of coast-water, with salinities even as low as 33·90 ‰(1), resting on the top of the Atlantic water. This coast-water has probably also been carried out by the cyclonic movement, which may have been somewhat complex.

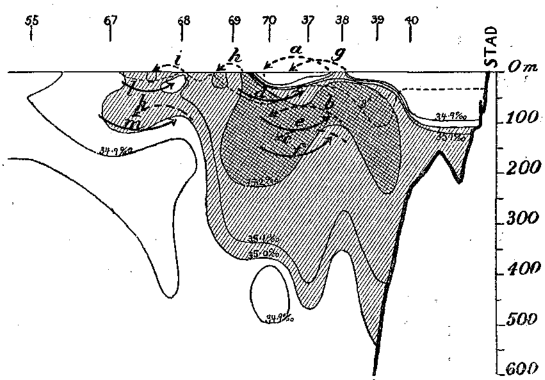

Fig. 35. Section seawards from Stad, June, 1904. The arrows indicate horizontal cyclonic vortex-movements (with vertical axes).

The process may have been as indicated in Fig. 35. The water-masses which were originally at Stat. 38 and Stat. 37 may have been carried by a horizontal cyclonic movement towards Stat. 70 and Stat. 69, as indicated by the broken-lined arrows *a*, *b*, and *c*, while the water-masses which were originally in the region of these stations have been carried by the same cyclonic movement towards Stat. 37 and Stat. 38, to replace the first-mentioned water, as indicated by the arrows *d*, *e*, and *f*. A little later a volume of coast-water has also been carried out by the cyclonic movement (as indicated by the arrow *g*) from the area between Stat. 38 and Stat. 39 towards Stats. 37 and 70, where it has accumulated into a thick layer resting on water with a temperature below 8° C., this having probably come from the west, as indicated by the arrow *d*. By the removement of the surface coast-water from Stat. 38, water with a salinity of even above 35·0 ‰ has been lifted to the surface at that place.

Small vortices have evidently also been formed farther west between Stat. 69 and Stat. 67, as indicated by the arrows *h*—*m*.

The section seawards from Aalesund, of February, 1901, is in the same region as the last mentioned section, only a little farther north (cf. Pl. II). It shows somewhat similar conditions and a similar great

(1) In Pl. XXIV A, Fig. 2, there is a misprint of 35·90 instead of 33·90 in the surface-salinity between Stat. 37 and Stat. 70.

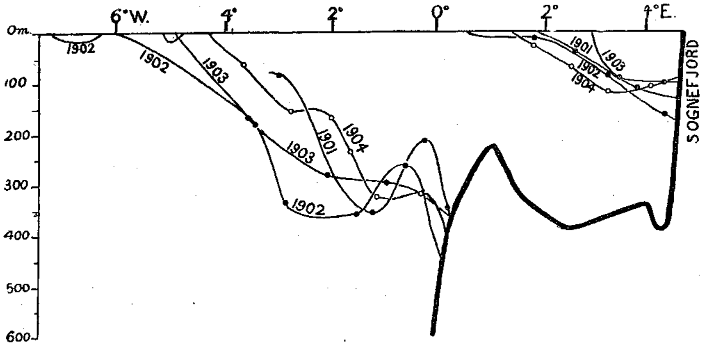

Fig. 36- Isohaline of 35·0 ‰ in the Section from the Sognefjord towards Iceland, May. 1901, 1902, 1903, and 1904.

"wave". The Atlantic water with salinities above 35·2 ‰ is here only present in the mass of water on the outer side of the wave, whither it looks as if it had then all been driven; but if there had been stations between Stat. 5 and Stat. 4, it is very possible that another volume of this water would have been found there.

The charts of the horizontal distribution of salinity and temperature in Pl. IV, ought to have been drawn differently, *e. g.* the water at Stat. 5 with salinity below 35·1 ‰ at 300 metres, and below 35·0 ‰ at 400 metres, might have come in from the south-west if there has been a cyclonic movement of the water, and should not have been drawn as isolated patches. But it is also possible that the Atlantic water with salinity above 35·2 ‰ has originally been nearer the surface, with a wider distribution towards Norway, but has suddenly, *e. g.* by a gale, been carried seawards and has accumulated at Stat. 8, in which case the underlying water at Stat. 5 has been lifted to form the "wave" seen in the section.

In most sections from the Sognefjord towards Iceland, a large "wave" appears, which in some sections, *e. g.* that of May, 1901 (Pl. XVI, Fig. 1), divides the water of the Atlantic Current almost into two separate masses. We consider it probable that this apparent "wave" in the sections is due to a great vortex-movement which frequently occurs in this region; but the axis of the vortex is not always in the same place. This is seen in Fig. 36, in which the isohalines of 35·0 ‰ have been introduced from the four sections of May, 1901, 1902, 1903, and 1904. The same great "wave" ocurred in May, 1905 (cf. Fig. 52). To judge from these sections, there may also be a great difference in the velocity of the vortex-movements. If the distances between the stations had been shorter the equilines

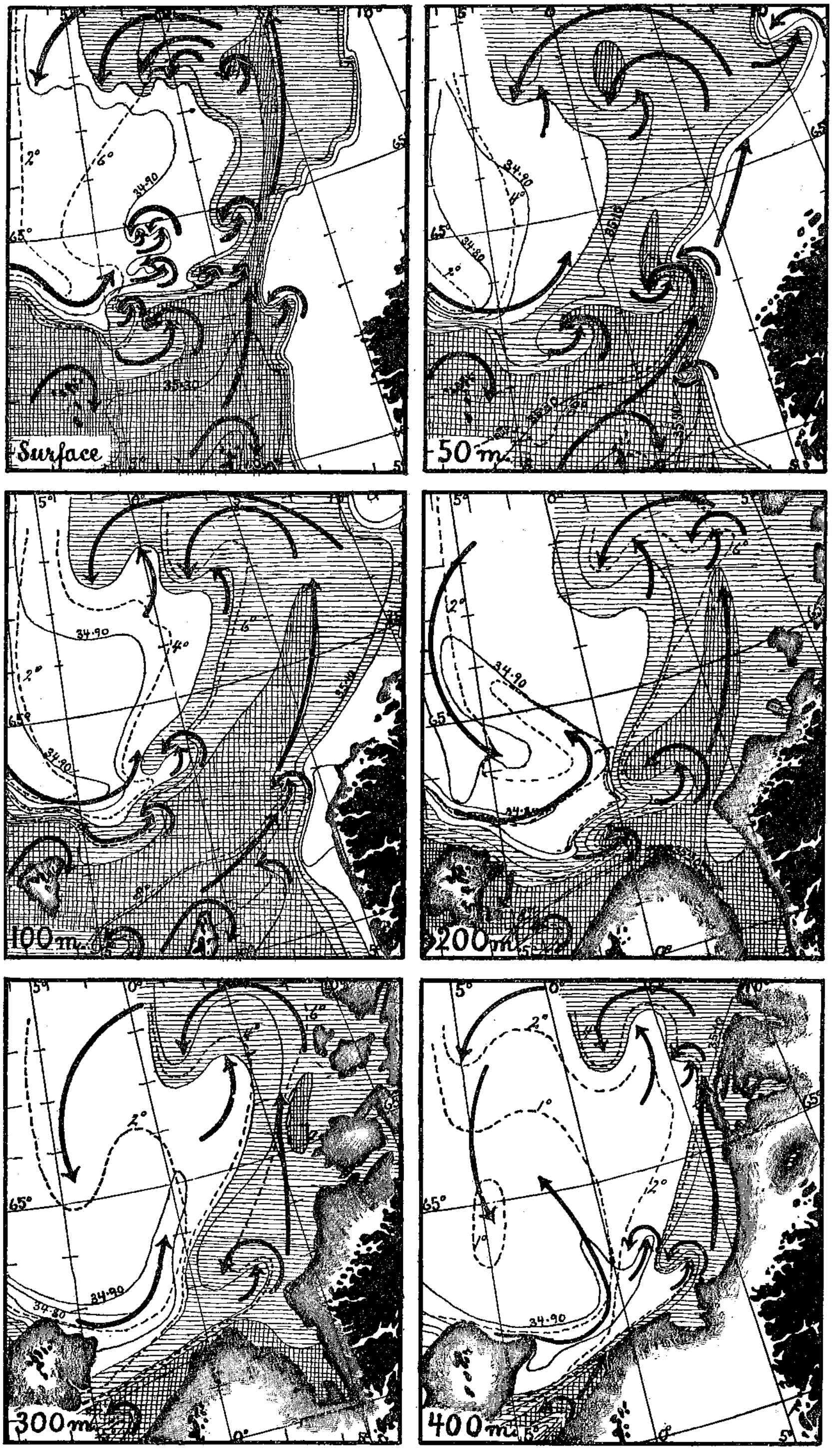

Fig. 37. Horizontal Distribution of Salinity and Temperature, and possible Vortex-Movements, May—June, 1904. Single hatching for salinity from 35·0—35·2 ‰; cross hatching for salinity above 35·2 ‰.

would probably have exhibited more smaller "waves", as is proved by the isohaline of May, 1904.

In Fig. 37 we have made an attempt to draw the charts of the horizontal distribution of salinity and temperature, for May & June, 1904, as we think they might be drawn, supposing that all the "waves" seen in the sections indicate cyclonic vortex-movements. This supposition is of course not correct, and there might be many vortices, especially small ones, in these charts, which did not exist; but nevertheless these charts may give some idea of what actually takes place in the sea. Only a comparatively small portion of the Atlantic Current, near the continental slope and the edge of the *continental shelf, is actually running forward* with more or less velocity. The greater part of the Atlantic water seen in a transverse section of the current, is in small or great vortex-movements, and is only to a small extent carried forward in the direction of the current; and it is gradually intermixed with the waters at the sides, in consequence of the complex movements.

The arrows in Fig. 37 indicate the directions of the impulses creating the vortex-movements.

We have taken the charts of May & June, 1904, as examples, there being most stations that year; but we think that the shape of the curves in many of the charts for the previous years, Pls. III—XI, could have been altered in the *manner indicated in* Fig. 37, *in order* to give more correct representations of the actual movements of the waters. But we consider it innecessary to go into further detail in this respect, as the manner in which the curves ought to be altered is easily seen.

3. Necessity of Numerous Stations.

All that has been said in the preceding pages proves clearly that the horizontal distribution of salinity and temperature in the sea is very complicated, and much more "irregular" than has hitherto been assumed. The conditions may often vary considerably at places with short distances between them. It is comparatively easy, for instance, to draw the isohalines and isotherms in surface-charts, if the observations be few and far apart. The equilines will then have very distinct and regular shapes, and it appears to be easy to draw general conclusions as to the horizontal distribution and movements of the different waters. But if there be numerous surface-observations, the task becomes much more difficult, and it is often impossible to say with certainty how the curves ought to be drawn. The picture thus obtained may be quite different from that which was based upon few observations; and it proves that the conclusions drawn from the few observations were more or less erroneous. As examples may be mentioned our surface-chart of May & June, 1904 (Pl. XII, or still better Fig. 37), as compared with that of July—September, 1900 (Pl. III). As a general rule it may be said that the more observations one has, the more complicated will be the picture obtained.

But this is the case not only on the sea-surface but also in the deeper lying strata. Our many observations from the several years prove clearly that the conclusions which might be drawn, as to the distribution of the waters, from observations taken at a few scattered stations, are of little or no value, because the conditions may differ entirely at two stations situated only a short distance from each other, cf. *e. g.* the difference between Stations 4 and 5 off Feje, in May, 1901 (Pl. XVI, Fig. 1).

The section across the Færoe-Shetland Channel, of May, 1903 (Pl. XXI B, Fig. 1) proves clearly the correctness of our view. The two Scotch Stations, *Sc. 19 B* and *Sc. 20 A*, were only some 10 miles apart, and were taken on the same day, May 31st, 1903(1). The following observations were made amongst others:

	Sc. 19 B		Sc. 20 A	
Depth	t° C.	S. ‰	t° C.	S. ‰
0	9·06	35·34	9·66	35·38
100	7·58	·26	8·70	·31
200	6.86	·17	8·30	·31
300	6·25	·15	8·22	·27
400	4·68	·02	7·70	·24
500	1·44	34·96	6·95	·18

(1) Stat. *Sc. 19 B* was taken May 31, 5 p. m.—7 p. m., in 60° 45′ N. Lat., 3° 50′ W. Long. Stat. *Sc. 20 A* was taken May 31, 2 p. m.—3 p. m. in 60° 38′ N. Lat., 3° 33′ W. Long.

These great differences give the equilines peculiar shapes with unusually steep slopes between the two stations. If Stat. *Sc. 20 A* had not been taken, one would have obtained quite a different picture of the conditions at depths between 300 and 500 metres, over the slope of the Shetland Bank.

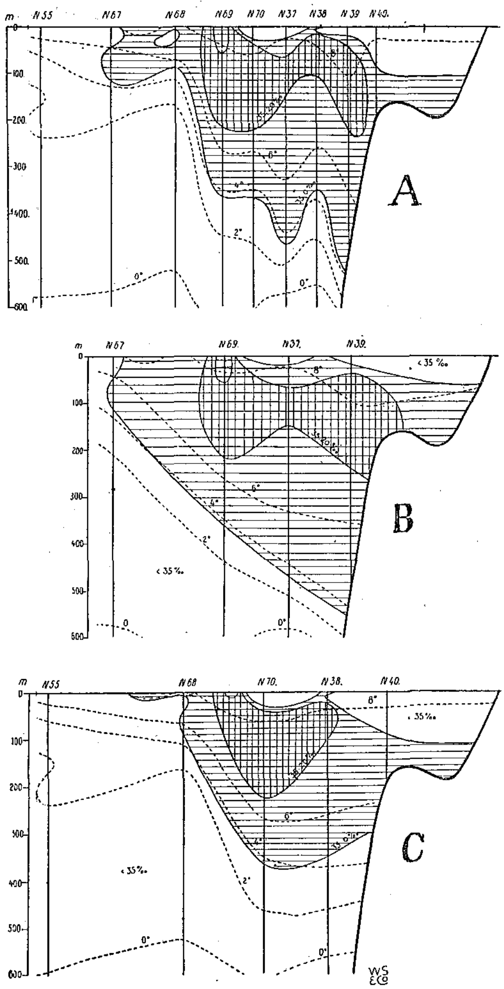

Fig. 38. Section seawards from Stad, June. 1904. Showing differences if every second station be left out.

Helland-Hansen has already pointed out [1904] how a single station taken between two others may entirely alter the appearance of the section. He has used as an example the section seawards from Stad taken in June, 1904 (Fig. 38, *A*, cf. Pl. XXIV A, Fig. 2), and has shown what very different pictures this section would give if every other station were left out, that is to say either leaving out Stats. 40, 38, 70, 68, and 55 (Fig. 38, *B*), or using these stations and leaving out the others (Fig. 38, *C*). These three figures ought to have given approximately the same picture, if they had been in any way trustworthy representations of the distribution of salinity and temperature in this part of the sea in June, 1904. The distances between the stations are no greater than might seem reasonable. In Fig. 38, *B* and *C*, the average distance between them is about 50 miles, while in Fig. 38, *A*, it is 25 miles, which is much shorter than is usually the case in oceanic sections. The sections in Fig. 38 B or C look quite as trustworthy, as many sections we have from the previous years and the distances between the stations are no greater; but if we had had only the one or the other set of stations, we should have drawn widely different conclusions as to the volume and movements of the water of the Norwegian Atlantic Current in that season, and both results would differ much from the conclusions in these respects drawn from the combination of all our stations, as represented in Fig. 38, A.

Another good example proving the importance of numerous stations at short intervals, is the section seawards from Aalesund taken in February, 1901 (Pl. XV, Fig. 1). During the seaward voyage, the Stations 3, 4, 5, 6 and 7 were taken; but at Stat. 7 the ship met with such a heavy gale that she had to turn back. On the return voyage, Helland-Hansen managed, however, in spite of the gale, to take Stat. 8, between Stats. 6 and 5. It is easily seen what an enormous difference this single station makes in the appearance of the section. Without it there would hardly have been any water with salinity above 35·2 ‰, and the equilines would have had quite a different shape. It is probable, however, that the section, even as it now is, gives no trustworthy representation of the real conditions at the time. More stations would certainly have altered the picture greatly. Stations between Stats. 4 and 5 might for instance have given another great volume of water with higher salinities.

The facts mentioned above are sufficient to prove how very difficult it is to obtain really trustworthy representations of the distribution of the different kinds of waters in the sea. They also prove how utterly inadmissible it is to draw conclusions as to extension or variations in the currents from a comparatively small number of observations, as some previous authors have had a tendency to do. It would, indeed, be a remarkable chance if such conclusions were not quite misleading.

As long as we do not know more about the "irregularities" in the distribution of the waters, whether they be boundary-waves or vortex-movements or something else, we cannot recommend any reliable method for determining the distribution and volume of the different waters in the sea. All we can say at present is: Take as many stations as possible with the shortest possible distances between them, and also, at any rate at some of the stations, repeat as often as possible the observations from the same depths at different hours of the day and night, in order to find out whether the different strata have changed their level during 12 or 24 hours.

With a great number of stations thus taken, one might hope to obtain sections giving fairly trustworthy representations of the real conditions at the time. Even then, however, it must be remembered that the conditions appear to change, often very rapidly, so that after some days, they may have altered much. If, for instance, numerous vortex-movements be formed in a current at certain intervals of time, it might make a great difference whether the section happened to be taken at a moment when these vortex-movements are well developed, or while there are none (cf. the difference between the sections seawards from Stad, June, 1903, and June, 1904).

It is also possible that by some such movements the waters of a current may be more or less cut off at certain moments, and be replaced by quite different water coming in from the side. This appears to be the case sometimes in the Færoe-Shetland Channel where in some sections the water of The Atlantic Current seems to be much reduced on the Shetland side, while at other times it seems to fill almost the whole channel.

VII. The Norwegian Atlantic Current.

Atlantic water, with salinities above 35·0 ‰, enters the Norwegian Sea through three openings, *viz.* the Færoe-Shetland Channel, the opening between the Færoes and Iceland, and Denmark Strait. The water passing through the two first-named openings advances northwards through the eastern part of the Norwegian Sea as the *Norwegian Atlantic Current* (or the "Gulf-Stream"), while the *Irminger Current* passes through Denmark Strait and enters the Norwegian Sea north of Iceland. As none of these entrances are deeper than 550 metres (about 300 fathoms),(1) Atlantic water cannot enter the Norwegian Sea below this depth; and if "35-water" is found at greater depths, it must be due to vertical movements of some kind. Mixing processes in particular will cause a sinking of the 35·0-isohaline in some parts of the sea.

The course and extent of the currents is chiefly studied by the distribution of temperature and salinity. We have pointed out above (p. 118 *et seq.*) that both the peculiar shape of the equilines, and the dynamical calculations, show that the Atlantic water to a great extent forms cyclonic (or anticyclonic) vortices, and that, as a consequence, great or small portions of this water flow in a direction more or less

(1) The northern branch of the *Irminger Current,* which enters the Norwegian Sea, is not so deep. It runs towards the north and north-east over the eastern part of the Iceland-Greenland Ridge, near the Iceland coast, and according to our section of it (Pl. XIV B, Fig. 2) its depth in August, 1900, (Stat. 14) was hardly more than 240 or 250 metres. The volume of this branch is evidently very small, as is proved by our section, and it is of comparatively little importance.

different to that of the Norwegian Atlantic Current in general. Such vortices are found in many parts of the Norwegian Sea, and, in our opinion, are quite ordinary phenomena, to be met with almost everywhere in the ocean. But if this be true, it is obvious that *we cannot draw conclusions as to the volume and development of the currents from the distribution of salinity and temperature alone.* A section taken transversely to the main direction of a current will thus often show a great lateral extension of the water characteristic of the current, but very great portions of this water will flow in other directions and only a small part of it in the main direction. Such a transverse section will therefore often cut the waters carried by the same current several times, and the apparent extension as shown by the isohalines and isotherms of the section may therefore be, say, twice as large as it would be if the vortices did not exist. We have already stated above (p. 128) that a great number of stations is necessary in order to procure sufficient material for a thorough study of the currents. It is necessary to have many stations not only along one sectional line, but also in different parts on both sides of this section. We must, in other words, have observations collected from different points of an area, and not only along one line; and the stations must not be too far apart. Our material does not fulfil these requirements, and it is therefore impossible for us to finally solve important questions as to the seasonal and annual variations in the strength of the currents.

1. Course and Extent of the Current.

The conditions in the area *between the Færoes and Iceland* are known from the Danish and Norwegian observations in August, 1902 (Pls. VII, XIX), May and August, 1903 (Pls. IX, X, XI B, XXII), and May, 1904 (Pls. XII, XXIV B). Some important features are common to all these diagrams and we shall especially call attention to the following: The equilines are crowded along the Færoe-Iceland Ridge; to the south of the ridge the salinities and temperatures are very high and the densities low as compared with the conditions north of the ridge; the equilines of the sections slope from the surface more or less steeply southwards towards the bottom; the charts show a southward "bight" in the equilines in 63°—64° N. Lat. and 10°—12° W. Long, this "bight" being situated just at a place where a submarine channel is found, separating two elevations or submarine "hills" (see Pl. I); the sections show a "tongue" of water, with salinities below 34·90 ‰, over the northern slope of the Færoe-Iceland Ridge. This "tongue" having a characteristic shape, and sloping more or less steeply southwards parallel with the equilines. In the following pages, we shall use the names "bight" and "tongue" in the sense here mentioned.

The sections of May, 1904, Pl. XXIV B, Figs. 3—7, may be especially referred to, as examples. The numbers af these Figures correspond to the situation of the sections, Fig. 3 representing the easternmost section, from the Færoes northwards, and Fig. 7 the westernmost section, not far from Iceland (cf. Pl. XII, Fig. 1). The sections in Figs. 3, 5, and 7, lie north and south, while those in Figs. 4 and 6, situated between them, are north-east and south-west in direction.

The shape of the isopyknals proves that the Atlantic water at the surface must run eastwards in relation to the water near the bottom,(1) *i. e.* the water has been flowing towards the east with velocities that have been decreasing downwards, or, if it has been running towards the west, with velocities that have been increasing downwards. The Atlantic water near the Færoes has undoubtedly been moving in an eastward direction (Fig. 3, Stats. Da. 2 and Da. 3); it forms a direct continuation of the water seen at the Stations Da. 5—Da. 9 in the sections farther west (Figs. 4 and 5). The temperatures, and probably also the salinities, decrease a little from the western Stations Da. 7—9 (Fig. 5) to the Stations Da. 2 & 3 (Fig. 3) farther east, as would be expected. Fig. 6 represents a section farther west in the region of the "bight" mentioned above. The distribution of the Atlantic water in this section differs much from that in the two sections to the east and is much smaller; the shapes of the isopyknals also prove that the conditions are different and that there is another movement of the waters. The waters with salinities above 35·1, and 35·0 ‰, evidently belong to the same volume of Atlantic water that occurred at Stations Da. 14 and Da. 15 in the section to the west (Fig. 7); and it has been separated from the much greater volume of Atlantic water in the sections to the east (Figs. 5 and 4) by the "bight" with water of lower salinities. We consider it, therefore, probable that the shape of the isohaline of 35·2 ‰ ought to have been somewhat altered in the charts for the surface, for 50 and 100 metres (Pl. XII). The "bight", with lower salinities, should have made a bend east of Stat. Da. 12 as in Fig. 39, and should not have passed west of this station as in Pl. XII. The isohaline of 35·1 ‰ at 200 metres should have had a similar shape, while at 300 and 400 metres the isohaline may have had shapes like those drawn in Pl. XII.(2)

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(1) In the following pages when discussing the direction and velocity of the water-movements, as indicated by the gradients of the isopyknals, we assume that the hydrostatic equilibrium conditional on the movements, has been attained.

(2) We think that there are indications of the "bight" having had similar shapes in other years also, especially in August, 1903, (Pl. X, surface & 50 metres, Pl.

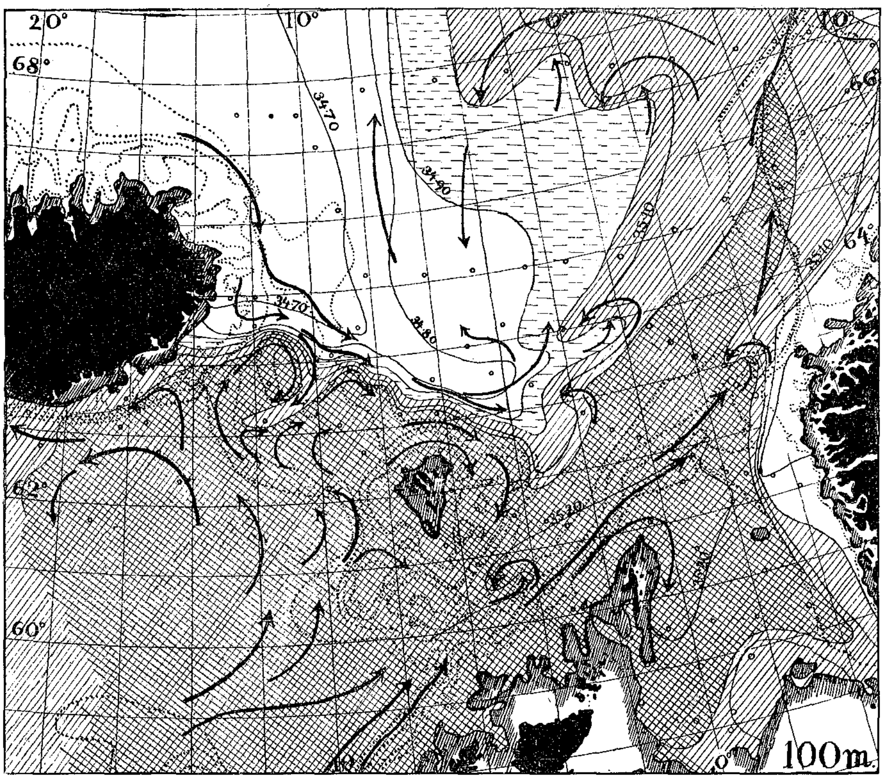

Fig. 39. Horizontal Distribution of Salinity at 100 Metres, May, 1904. The arrows indicate the probable movement of the waters at this level.

The assumption that it is the same volume of Atlantic water at Stat. Da. 12 as at Stats. Da. 14 and Da. 15, agrees well with the temperatures and salinities. Let us assume that the course of the Atlantic water has been from Stat. Da. 15 to Da. 12, and thence south of Da. 14, as indicated by the arrow in Fig. 39.

The following Table shows a decrease of temperature, and to some extent also of salinity, from Stat. Da. 15 to Da. 12. Stat. 14 is situated nearer the centre of the vortex; but even here there is upon the whole a decrease from Stat. Da. 12. This seems to indicate that the Atlantic water has been moving in the direction indicated in Fig. 39, and has been somewhat cooled on its way, and that there has been a slight intermixture with the water on the outer side of the anticyclone, which has lowered the salinity a trifle.

XXII, Figs. 5 & 6), and perhaps also May, 1903 (sections Figs. 6 & 7, Pl. XXI B). In the latter case the movement of the water at Stat. Da. 13, has probably had an eastward component (Fig. 7), which, however, is not seen in Fig. 6 (Pl. XXI B), probably because the distance between the stations has been too great.

Depth.	Da. 15.	Da. 12.	Da. 14.
0 Metres.	7·35 ° C. 35·25 ‰	7·26 ° C. 35·25 ‰	7·13 ° C. 35·25 ‰
25 —	7·38 ° C. 35·26 ‰	7·20 ° C. 35·25 ‰	7·09 ° C. 35·25 ‰
50 —	7·38 ° C. 35·26 ‰	7·11 ° C. 35·24 ‰	7·01 ° C. 35·24 ‰
100 —	7·40 ° C. 35·26 ‰	6·80 ° C. 35·20 ‰	6·94 ° C. 35·23 ‰

The sections in Figs. 6 and 5 (Pl. XXIV B) also prove that the movement of the water has been as assumed above. The water below 250 metres between Stats. Da. 13 and Da. 12 (Fig. 6) must have come from the "bight" (see chart for 300 metres Pl. XII); it cannot have come from the sea to the east of it, as in the sections shown in Figs. 5 and 4 there is much less of this kind of water. The inclination of the isopyknals between the two stations prove that the surface-layer must have been moving slowly towards the west or north-west as compared with the deeper strata, *i. e.* the relative movement of the strata must have had a north-westward component (at right angle to the direction of the section) near the surface. The explanation is probably that between the two Stations (Da. 13 and Da. 12) the bottom-strata, below the level of 250 metres, have been moving slowly along the line of direction of the section, or slightly more towards the south, while the upper strata of Atlantic water have been moving more towards the south-west or west, as indicated in Fig. 39. The isopyknals between Station Da. 12 and Station Da. 11, to the north, slope in the opposite direction, and indicate that the surface-layer has been moving more rapidly towards the south-east (se Fig. 39) than the deeper strata.

I this manner we get a fairly rational system of movements. The water in the "bight", with comparatively low salinities, moves in a southerly direction. Near the surface this water makes a wider circuit, east of Stat. Da. 12 (see Fig. 39): but near the bottom it runs more directly southwards, following the depression between the two elevations of the submarine ridge, rising above the level of 400 metres (see chart for 400 metres, Pl. XII). The surface-layers of this southward-flowing water are checked by Atlantic water running towards the north-east along the eastern side of the bight (see Fig. 39); but the deeper southward-flowing strata, with salinities slightly above or below 34·9 ‰ and with temperatures between 0° and 4° C., are less checked by the Atlantic water, and advance farther southwards along the above-mentioned channel or depression, and may to some extent cross the Færoe-Iceland Ridge and sink into the northernmost part of the deep basin of the Atlantic [J. N. NIELSEN, 1904 and 1907]. The Atlantic water immediately to the east of the "bight" moves at first northwards over the higher portions of the ridge, and near 64° N. Lat., above the north-eastern side-slope of the ridge, will be deflected sharply towards the east.(1) This east-flowing Atlantic current passes to the north of the Færoes; its northern boundary is very sharply defined, and in about 8° W. Long. often makes another bight similar to the first, but much less developed (cf. Pls. VII, IX, XII).

Fig. 7, Pl. XXIV B, demonstrates the conditions somewhat farther west. At Stations Da. 14 and Da. 15, more of the Atlantic water, with salinities above 35·2 and 35·1 ‰, is seen than at Stat. Da. 12 of the former section. The bottom-layer at Stat. Da. 13, below 250 metres, is the same as at Stats. Da. 13 and 12 of that section (Fig. 6). It has come from the north-east. The shapes of the isopyknals show, that the surface-layers between the Stations Da. 13 and Da. 15 must have had a southwestward movement as compared with the deeper strata; the gradients are not very great, evidently because the section in this part runs obliquely to the direction of the movement, more along the current than across it.

Farther north, between Stations Da. 15 and Da. 16, the isopyknals slope very steeply in the opposite direction, proving that the surface-layers have been moving in a direction that has had a very great eastward component as compared with the movement of the bottom-strata. If such had not been the case, we must have assumed that the velocity of the current was much greater near the bottom than at the surface; but this is highly improbable, for we should then expect that the Atlantic water near the bottom at Stat. Da. 15. had been swept away by water of lower salinity, coming from the "bight". We may therefore draw the following conclusions:

The Atlantic water between Iceland and the "bight" moves in an anticyclonic direction (see Fig. 39), with maximum of velocity near the surface. A sharp boundary between this warm, salt Atlantic water and the colder, more diluted waters, coming southwards along the eastern coast of Iceland, is always found near Vestre Horn (64° 15′ N. Lat., 14° 50′ W. Long.) [J. N. NIELSEN, 1908, p. 13]. The Atlantic water met with at this locality thus appears to come from the south or south-west. But farther west, along the southern coast

(1) The course of this current is a good illustration of the dependence of the distribution of the waters upon the configuration of the bottom. The Atlantic water coming from the Atlantic side of the Færoe-Iceland Ridge, extends farther towards the north-east over the highest portions of this ridge, until it meets the water of the Iceland Arctic Current on the north-eastern side-slope. Wherever there is a channel or an embayment in this slope, the water of the Arctic current will run south or southwestwards and sweep away the Atlantic water.

of Iceland, the Danish investigations have proved a westward movement of the Atlantic water. A division of the Atlantic water consequently occurs somewhere off the southern, or rather south-eastern coast of Iceland,(1) one part of it—probably the larger part—moving westwards, and the other part moving towards the north-east as far as the latitude of Vestre Horn, where it is turned more eastwards, forming the anticyclonic vortex south of $64^1/_2$(2) N. Lat., and west of 10 or 11° W. Long. (see Fig. 39). The conditions in the area round the "bight" are quite analogous to those found in the Færoe-Shetland Channel.

The above conclusions have been based upon the observations of May. 1904. But all the observations of May and August, from 1902 to 1904, show altogether similar conditions, only with slight variations in some details. We are therefore justified in assuming that our conclusions hold good for the summer season in general. It is possible that the conditions are somewhat altered in the winter season. This question cannot be settled, owing to lack of observations; but it is not probable that there are any great variations in the courses of the currents.

The Atlantic water above the Færoe-Iceland Ridge west of the Færoes, has, thus, to a great extent an eastward movement. A great part of this Atlantic water will run eastwards north of the islands, as is seen in the section, Fig. 3, Pl. XXIV B, at the Stations Da. 2 and Da. 3. This water will generally be deflected to the right, and

(1) The probability of such a division also in the surface drift current, is proved by the 14 drift-bottles mentioned by J. N. NIELSEN [1908, p. 8], which were thrown out in the sea south-east of Iceland between 15° 38′ and 16° 39′ W. Long., and 62° 55′ and 63° 36′ N. Lat. Three of them were found along the south coast of Iceland, to the west, the rest had drifted eastwards, and were found, one on the Shetlands, nine along the Norwegian Coast, and one on the Murman Coast.

C. RYDER [1901] mentions a number of drift-bottles which were thrown out in the area south-east of Iceland, between 10 and 15° W. Long. and between 61 and 64° N. Lat. Most of them drifted towards the north-west and west, to the south coast of Iceland, while some of them were carried eastwards towards the Færoes and Norway.

(2) It may be that the northern edge of this anticyclone may sometimes even approach 65° N. Lat. At Stat. 10, July 28, 1900, in 64° 53′ N. Lat., 10° 0′ W. Long., we found Atlantic water with salinities above 35·20 ‰ down to 160 metres, and above 35·0 ‰ to nearly 200 metres (cf. Pls. III, and XIV A, Fig. 1).

will run into the Færoe-Shetland Channel close along the slope of the Færoe Platform as Helland-Hansen has pointed out [1905a]. J. N. Nielsen has suggested [1904] that this Atlantic water north of the Færoes moves directly eastwards, and joins the main part of the Norwegian Atlantic Current north and north-west of the Shetlands. This may perhaps sometimes happen (1); but as a rule it is not the case. The observations from May and August, 1902 to 1904, show clearly a southward bend of the equilines, proving that water from the Norwegian Sea enters the Channel from the north, and that the Atlantic water is moving southwards along the eastern side of the Færoes.

Our section, Pl. XVIII, Fig. 1, from June and July, 1902, demonstrates this southward or south-eastward course of the current north-east of the Færoes. Stat. 43 was on the slope north-east of the islands, in 62° 28′ N. Lat. and 5° 14′ W. Long. The depth was 420 metres. Stat. 42 (in 62° 37′ N. Lat. and 2° 36′ W. Long.) was just in the middle of the northern entrance to the Færoe-Shetland Channel(2). The steep inclination of the isopyknals between these two stations proves that the Atlantic water, as well as the Arctic water, between them, has been running in a southerly or south-easterly direction, with velocities, which were considerably greater in the upper strata than at 400 metres. It is impossible that the water between these two stations can have been moving in an eastward direction.

The Scottish observations form especially a good material for studying the conditions of the *Færoe Shetland Channel.*

We shall once more take the sections May, 1904 (Pl. XXIV B), as an example. Fig. 1 represents a Scottish section from Fair Isle to the south of the Færoes (see Pl. XII), the observations being made between the 26th and 28th of May. Fig. 2 shows a section farther north, from north of the Shetlands to the Færoes, the Stations being taken on the 29th, 30th, and 31st of May. Fig. 1 shows two deep, narrow wedges of warm salt Atlantic water, one close to the slope of the Orkney-Shetland Bank, and the other in the central part of the Channel. They are separated

(1) Our charts for November, 1903, in Pl. XI, might for instance, give the impression that such was the case at that time; but it is very doubtful whether the isohalines and isotherms are correctly drawn, especially in the Færoe-Shetland Channel, as the stations were far too few, and it is equally probable that there has been a southward current along the Færoe side of the channel.

(2) The section goes very nearly due east from Stat. 43, to Bremanger in Norway. Stat. 39 was in 62° 23′ N. Lat. and 2° 35′ E. Long., while Stat. 52 was taken 16 days later (July 16th, 1902) in 62° 1′ N. Lat. and 4° 0′ E. Long.

by a wedge of cold water from below, with salinities between 34·9 and 35·0 ‰; the same kind of water also being found close to the Færoe side-slope, below 500 metres. The isopyknals rise and fall very abruptly, and their inclinations show, that the Atlantic water on the eastern side of the Channel (Stat. Sc. 20 A) was moving northwards at a great rate. The opposite inclination of the isopyknals between the stations Sc. 19 B and Sc. 19 A indicates a movement southwards, while again the movement of the waters between Sc. 19 A and the Færoes had comparatively a northward component. The expression "directions of the currents" means here the movement of the surface layers in relation to the deeper strata. It is possible that all the Atlantic water seen in the section was moving northwards, with velocities that decreased downwards, both between Sc. 20 A and 19 B, and between Sc. 19 A and the Færoes; while between Sc. 19 B and 19 A the velocities increased downwards.

But if this were correct, the velocities in the deeper strata between the two last-mentioned stations must have been very great. The fact that the maximum temperature and salinity occurred at the surface and not at intermediate depths, seems, however, to indicate that this was not the case; and the only probable explanation is therefore, that the water at this place (between Sc. 19 B and 19 A) was really moving southwards with velocities that decreased from the surface downwards. There has then been a cyclonic vortex in the southern part of the channel in May, 1904, of the same kind as those mentioned in Chap. VI, *f*, and illustrated in Fig 37. This is clearly demonstrated by the charts, *e. g.* from 200 to 600 metres, on Pl. XII. The movements of this vortex must have been very rapid, but the vortex itself would be rather narrow, as will be seen by a comparison of Fig. 1 with Fig. 2 (Pl. XXIV B). In the latter figure no wedge of Atlantic water occurs in the central part of the section, while that on the eastern side of the Channel seems to be much broader than it was in the southern section. It is possible though not probable, that observations between Stations Sc. 13 A and Sc. 14 A would have altered the figure considerably. The inclination of the isopyknals, as they are drawn in Fig. 2, shows a northward movement of the Atlantic water in the eastern half of the Channel (Sc. 15 A—Sc. 13 A), a small southward component of the movement between Sc. 15 A and Sc. 15 B, and between Sc. 15 B and the Færoes again a movement towards the north, or rather towards the north-east or east. The Atlantic water in the section in Fig. 3 (Pl. XXIV B), at the Danish Stations 2 and 3, was observed on the 9th and 10th of May, *i. e.* three weeks before the Scottish observations were made. During this time considerable changes may have taken place. It is probable that Atlantic water, similar to that found north of the Færoes on May 9th, flowed towards the south or south-east during the latter part of the month, but only for a comparatively short distance, until it met with the Alantic water coming from the south and southwest, which forced it eastwards across the Channel.

In August, 1903 (Pl. XXII), the conditions in the Færoe-Shetland Channel were, upon the whole, analogous to those found in May, 1904. The water that had come round the Færoes to the north seemed then to advance farther south than in the latter season, but otherwise the conditions were very similar. It is difficult, however, to determine whether the vortex in the southern part of the Channel had a cyclonic direction as supposed in May, 1904, or an anticyclonic direction, as drawn on the charts on Pl. X. The section (Pl. XXII, Fig. 2) might in both cases have had the same appearance. More investigations, especially farther south, would have been necessary in order to settle this point.

The sections of May, 1903 (Pl. XXI B), show some peculiarities. Fig. 2 is especially interesting, and shows a wedge-shaped mass of very salt Atlantic water east of the Færoes. This is shown only by the observation at the Danish Station 1, made a month before the Scottish observations on which the section is otherwise based. It is very probable that great changes have taken place between May 2nd (Da. 1) and 30th (Sc. 15 A and 15 B), and that an erroneous representation of the conditions has been obtained by introducing the Danish station into the section together with the Scottish stations. If Stat. Da. 1 had been left out, Fig. 2 would have had very nearly the same appearance as Fig. 1. If this be done, these figures will indicate that the Atlantic water in the eastern half of the Channel was moving northwards, and the water with lower salinities in the western half southwards. Much the same conditions are found in the sections of August, 1902 (Pl. XIX, Figs. 2 and 3). At that time the central part of the Channel was covered with a surface-layer of water with comparatively low salinities (below 35·0 ‰), which had come from the north and was remaining, almost stationary, in the centre of the cyclonic vortex formed by the southward current along the Færoes and the northward current along the Shetland side [HELLAND-HANSEN, 1905a].

The observations dealt with here may be summarized as follows:

The main portion of the Norwegian Atlantic Current enters the southern part of the Færoe-Shetland Channel running towards the north-east, or to some extent east. It generally keeps close to the Shetland Bank. Vortices are sometimes formed in the Channel (as in May, 1902 and 1903). A smaller volume of Atlantic water enters the northern part of the Channel, running towards the south or south-east (or perhaps sometimes due east), and joining the main body of the current, which thus, in the southern part of the Norwegian Sea, consists of water that has come from both the south and the north of the Færoes. The conditions in the Channel may change rapidly, even down to great depths. In August, 1903, for instance (Pl. XXII, Fig. 1), the bottom-water generally found there, had quite disappeared from the southern part of the Channel; and at 1 000 metres, the salinity was then 35·03 ‰, and the temperature 1·7 °C., instead of 34·92 ‰ and about — 1 °C. [ROBERTSON, 1905. Cf. HELLAND-HANSEN, 1905a].

Offshoots into the North Sea, from the Norwegian Atlantic Current, are met with north and south of the Shetlands. It will be seen in the charts for August, 1902 (Pl. VII), May, 1903 (Pl. IX), August, 1903 (Pl. X), November, 1903 (Pl. XI), and May, 1904 (Pl. XII), that the isohalines make a bend east- and southwards at the Shetlands.

Between the Orkneys and the Shetlands (round Fair Isle) there are generally lower salinities than on both sides, in the Channel and in the North Sea. ROBERTSON [1905, 1907] and others have suggested that the chief influx of Atlantic water into the North Sea, takes place through this entrance south of the Shetlands; but it seems more probable that the chief influx takes place from the Norwegian Sea, north of the Shetlands as has been suggested by Helland-Hansen [1905 a]. In this region a continuous mass of very salt water is running southwards towards Scotland during most seasons in which investigations have been carried on (cf. Fig. 39). There are obviously rather great variations in this influx, seasonal as well as annual. From the Scottish observations in 1902 Helland-Hansen discovered [1902, 1904, 1905, a] that the bottom-water of the northern North Sea is Atlantic water that has come round the Shetlands southwards, in autumn and winter. It has got temperatures below 7° C., partly by vertical convection currents in winter(1), and partly by a slow transmission of the low temperatures (by conduction) from above.—Some Atlantic water is also given off to the Norwegian Channel, where recent current-measurements have shown a movement towards south or south-east in the deeper strata (see Chap. VIII).

In the Norwegian Sea, the main body of the Atlantic Current keeps close to the continental slope. The great difficulty in determining the volume of the current in a transverse section, on account of the irregularities caused by the vortex-movements and possible subsurface waves, has already been pointed out; and it was stated that vortices were in all probability often formed at various parts of the Norwegian Sea, *e. g.* north of the Shetlands (62° N. Lat.), off Söndmøre (63°—64° N. Lat.), and off Lofoten (67°—68° N. Lat.). Such vortices have obviously some connection with the bathymetrical features of the sea-basin, as also with the currents on both sides.

The Norwegian Altantic Current is deflected to the right by the rotation of the Earth. When leaving the Færoe-Shetland Channel it passes *Tampen* (see Fig. 8) and crosses the entrance to the Norwegian Channel in a direction more easterly than northerly. In about 63°

(1) The bottom-water of the northern North Sea has thus, as to its formation, some resemblance to the bottom-water of the Norwegian Sea and the Barents Sea.

N. Lat. the direction of the continental slope alters from east and slightly north to almost due north; and the direction of the current must therefore be altered too. It seems probable that a part of the current is thereby forced backwards so as to form a cyclonic vortex, as shown in Fig. 37. Above the *Vöring-Plateau* (Fig. 8), the eastern portion of the current follows the continental slope towards the north and north-east, while the western part of it is deflected towards the north-west and west, along the *Helgeland Ridge.* The sections seawards from Lofoten therefore always show a much larger sectional area of Atlantic water than the sections farther south, as both branches of the current are cut by the sections, the northward one almost transversally, and the westward one more or less longitudinally. The latter branch is clearly shown in a number of the charts (Pls. III, V, VI, VIII, IX, X, XII, *i. e.* in all charts in which observations along lines traversing the Norwegian Sea in these latitudes have been introduced). The westward movement by and by becomes more southward. This part of the Atlantic water meets with the water from the East Iceland Arctic Current, and is probably again carried northwards (cf. Fig. 39). In this manner a cyclone is formed in the southern half of the Norwegian Sea, with its centre at from 65 to 66° N. Lat. and from 0 to 4° W. Long. This is the most characteristic feature of the southern half of the sea. The cyclone is evidently a constant phenomenon subject only to variations in detail. Being a feature of great importance, it will be treated more fully in a later chapter (X).

Water from the Norwegian Atlantic Current covers the deeper hollows and submarine fjords of *the continental shelf* off western Norway. Between Nordmöre (Storeggen) and the Lofoten Bank, the "edge" of the shelf, where the continental slope begins, lies from 300 to 400 metres below the sea surface. All parts of the shelf lying deeper than 200 metres are covered by water with salinities of more than 35 ‰, as are also all those parts of the shelf which have a depth of 200 metres or more. This is seen in all the charts for 200 and 300 metres; the Atlantic water occurs everywhere along the Norwegian coast close to the 200 and 300 metres' contours in these charts. The same Atlantic water will be found in the deeper parts of the Norwegian fjords, if these are not separated from the Ocean by a high threshold or sill at the entrance. This Atlantic water in the fjords and over the continental shelf is always covered by the coastal water. The coastal water (which will be especially discussed in the next Chapter) has salinities which constantly increase from the shore seawards, owing to intermixture with the Atlantic water below. Some part of the Atlantic water is thus carried away by the upper water-layers, with lower salinities, and has to be replaced by renewed influx. In this manner a constant, though slow, eastward influx of water from the Norwegian Atlantic Current will be created, and pass along the bottom across the continental shelf towards the coast, as a kind of "Reaction-Current", under the top-layers of coast water.

The main part of the Atlantic Current follows *the continental slope,* as already mentioned. This slope is almost everywhere rather steep down to 1 000 metres or more; and the upper part of it is covered with Atlantic water. The depth of the current, or in other words, the depth to which the slope is covered by Atlantic water, varies considerably. When comparing all the different sections of Norway, it will be seen that the lower isohaline of 35·0 ‰ is generally much deeper in the northern sections, off Lofoten, than in the southern, off Feje or Stad. In the sections off Feje (Sognefjord), the northern part of the Shetland Platform—"Tampen"—is seen as a submarine ridge (*e. g.* at Stat. 3, Pl. XVI, Fig. 1). The 35·0-isohaline will be found west of this ridge at depths varying between 350 metres (May, 1901, Pl. XVI) and 550 metres (November, 1903, Pl. XXIII), the depth being generally about 400 metres. The same isohaline, in the Lofoten Sections, is at depths between 450 metres (May, 1904, Pl. XXIV A) and 900 metres (February, 1901, Pl. XV), generally about 700 or 800 metres. Coincidently with the sinking of the isohaline of 35·0 ‰ northwards, there is a decrease in the maximum salinities of the Atlantic water. Great masses of water with salinities above 35·2 ‰ are generally found in the southern part of the Norwegian Sea, but this high salinity gradually disappears on the way northwards, only very little of it being found, upon the whole, in the sections from Lofoten. Still farther north, off Finmark or Bear Island, such high salinities are very rarely met with, and even water with salinities above 35·1 ‰ is only seldom observed there. This proves that the Atlantic water must have been intermixed with other waters to a very great extent. We have already mentioned that coast water and Atlantic water are intermixed on the eastern side of the Atlantic Current; but the Atlantic water is intermixed to a still greater extent with Arctic water and with central waters on the western side of the current, and with bottom-water on its underside.

The Arctic water is brought, by the East Iceland Arctic Current along the northern slope of the Færoe-Iceland Ridge, into contact with the Atlantic Current already in the northern mouth of the Færoe-Shetland Channel. By the numerous great and small horizontal vortices (with vertical axes) formed during the northward course of the Atlantic Current (see Chap. VI, *f*, and Fig. 37), its waters must be continually more and more intermixed with the Arctic water and with what we have called the central waters which come into these vortices from the west.

The sinking of the isohaline of 35·0 ‰ to the great depths demonstrated by the Lofoten sections (mentioned above) proves that the intermixture of the Atlantic water with the underlying bottom-water is very considerable. It must essentially be due to the occurence of numerous vertical vortex-movements (with horizontal axes). By the horizontal vortex-movements a similar intermixture with the underlying bottom-water is also produced.

It thus appears probable that vortex-movements, both horizontal and vertical, are of the very greatest importance in the whole dynamic economy of sea-currents; and they probably also explain to a very great extent the enormous resistance in the sea, which, as all theoretical calculations prove, the currents have to overcome, since otherwise they would flow with great velocity (cf. NANSEN, 1905).

We have previously (Chap. VI) pointed out the probability that great oscillations often occur in intermediate waterstrata. During such oscillations, the boundaries between the various waters would move up and down, at more or less regular intervals of time and with different amplitudes. As a result of such oscillations, parts of the continental slope would be alternately covered by Atlantic water and by colder water from below. It seems very likely that in the southern part of the Norwegian Sea the water covering the continental slope, *e. g.* between 400 and 500 metres, changes rapidly in this manner and that very different conditions may be found within short intervals of time at these places. In the upper parts of the slope and on the continental shelf, the conditions are obviously very uniform, because they are always covered by the uniform Atlantic water; and the character of the water will not be appreciably altered, even if similar oscillations occur there also.

The Atlantic water can only flow into the Norwegian Sea across the submarine ridge between Scotland and Greenland,(1) and most of it passes through the Færoe-Shetland Channel, as was pointed out above. As a rule the inflowing water does not even fill the whole of this narrow Channel; but it runs towards the north-east, chiefly along the eastern side-slope of the Channel.

The Norwegian Sea, with its adjacent areas, the North Sea, the Barents Sea, and the North Polar Sea, may be considered as one enclosed sea, with only one great entrance, that between Scotland and Greenland. Bering Strait is so shallow (only about 40 and 50 metres) and narrow that it may be left out of consideration. Smith Sound, Jones Sound, and Lancaster Sound are deeper, and some water flows out through them, especially through the last-named; but even they are of little importance as compared with the opening between Scotland and Greenland.

As the evaporation from the sea-surface is not in excess of the precipitation over this region, the water running into this enclosed sea must again run out of it; and the amount of salt carried by the inflowing Atlantic currents, and that carried by the outflowing currents through the above-mentioned openings, must be very nearly equal. In addition to the inflowing sea-water, this enclosed sea also receives great quantities of river-water from northern Europe, Asia and America.

Let us try to follow the course of the Atlantic water in the Norwegian Sea.

There are three principal openings through which water is carried out of the Norwegian sea-basin(2):

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(1) The quantity of water coming in through the Straits of Dover is so small that it may be left out of consideration here.

(2) We do not here consider the offshoot of the Atlantic Currents running into the North Sea, by the Shetlands, mainly north and east of them. The water-masses carried by this current return to the Norwegian Sea again, west of Norway, mixed with the waters of the Baltic Current.

(1) The opening betweeen Norway and Bear Island(1), where the *North Cape Current* runs into the Barents Sea. The masses of this current either returns to the Norwegian Sea again, south of Spitsbergen, or the greater part of them flows into the North Polar Basin, and returns with the East Greenland Polar Current.

(2) The opening between Spitsbergen and Greenland. Here a narrow branch of the *Spitsbergen Atlantic Current* crosses the Spitsbergen-Greenland Ridge, and runs into the North Polar Basin along the continental slope off north-western and northern Spitsbergen. According to our present knowledge, it is evident that the quantity of water carried by this current out of the Norwegian Sea is much smaller than the quantity brought into it by the Greenland Polar Current. The waters of the latter are chiefly the returning water from the Spitsbergen Current, and from the Barents Sea (running into the North Polar Basin), which have been mixed with the water from the Siberian and American rivers(2).

(3) The opening between Iceland and Greenland, through which the main outflow finds its way across the Iceland-Greenland Ridge.

(4) The opening between the Færoes and Iceland. Only very little water finds its way across the ridge out of the Norwegian Sea; but it was mentioned above that in the "bight" a small outflow does evidently occur.

These different outflows contain extremely little Atlantic water with salinities above 35 ‰. Such water is only found in the two currents through the first two openings mentioned(3), and that in such small quantities as to be quite insignificant compared with the quantities of Atlantic water carried into the Norwegian Sea. It is consequently obvious that by far the greater part of this water becomes mixed with other waters inside this sea-area, which thus change its

(1) A little Atlantic water runs towards the north-east between Bear Island and Spitsbergen; but it is insignificant and most of it returns south of South Cape. We leave it therefore out of consideration.

(2) A much smaller part of this mixed water runs out through the sounds of the American Arctic Archipelago, chiefly through Lancaster Sound.

(3) Atlantic water with salinity of over 35·0 ‰ probably also occurs under the Greenland Polar Current crossing the Iceland-Greenland Ridge; but this comes from the Irminger Current. The warmer water underlying the Greenland Polar Current flowing out of the Norwegian Sea has lower salinities (see later).

character, and cause its transformation into other kinds of water, by the time it leaves this sea.

After having been intermixed more or less with Artic water (to form the central water), some small part of the inflowing Atlantic water probably finds its way, from the western region of the great cyclonic vortex-movement of the southern Norwegian Sea, through the opening between Jan Mayen and Iceland, and may join the strata that underly the East Greenland Polar Current, flowing out across the Iceland-Greenland Ridge; but by far the greater part of the Atlantic water seems to run northwards, through the sea between Jan Mayen and Norway (cf. the section Pl. XIV A, Fig. 2.)

If we look only at the southern area of the Norwegian Sea, south of a line drawn from Jan Mayen to Vesteraalen, and east of a line from Jan Mayen to Iceland, the quantity of water passing northwards through the transverse section along the former line, will be chiefly determined, on the one hand by the *importation* of waters by the Atlantic Current from the south, by the East Iceland Arctic Current from the northwest, and by the Baltic Current—the last-named being the rainfall over Northern and Central Europe (mixed with Atlantic water)—, and on the other hand by the *exportation* of water westwards through the section along the line from Jan Mayen to Iceland(1). It is not probable that the outflow through the latter section will be greater than the inflow in the shape of the Iceland Arctic Current through the same section. We must consequently assume that the quantity of water passing northwards between Jan Mayen and Norway is at least equal to that flowing in across the ridge between Scotland and Iceland, *i. e.* the waters of the Norwegian Atlantic Current.

We find, however, only relatively small quantities of Atlantic water in the Norwegian Sea north of 70° N. Lat. (from Jan Mayen to Northern Norway); and we must therefore conclude that the Norwegian Atlantic current has lost its original character, and that its movements have been transferred to waters which are no more recognisable as Atlantic waters. In other words, the quantities that enter

(1) The outflow across the Færoe-Iceland Ridge is so small that it cannot count for much as compared with the other water-masses flowing in and out.

the northern half of the Norwegian Sea between Jan Mayen and Norway, as more or less transformed water-masses, must be almost equal to those that entered the southern half.

Thus we may account for the small quantities of Atlantic water, with salinities above 35 ‰, that are found in our *northern sections.* The Atlantic Current running northwards from Lofoten along the continental slope off Vesteraalen and western Finmark, divides at 71°—72° N. Lat. into two branches; one of them, the *North Cape Current*, running eastwards into the Barents Sea, and the other proceeding northwards along the continental slope off Bear Island and Spitsbergen, and forming the *Spitsbergen Atlantic Current.* The first of these is seen in the sections between Norway and Bear Island, of August, 1900 (Pl. XIV A, Fig. 3), and March, 1901 (Pl. XV, Fig. 4). The August section shows a very small quantity of water with salinities slightly above 35·1 ‰, but the March section none at all. The inclination of the isopyknals proves clearly in both sections that the surface-layers have an eastward movement as compared with the deeper strata. The gradients are steeper in the March section than in the August section indicating that the surface-current has then been running at a greater speed. But in both of them the steepest gradients, and consequently the greatest velocities, are found on the right side of the sections, close to the Norwegian coast in the coast-waters, with salinities below 35·0 or even 34·9 ‰.

The northernmost branch of the Atlantic Current is represented in our observations only by a short section off Bear Island, in September, 1900 (Pl. XIV A, Fig. 4), and by a longitudinal section running southwards from a point west of Bear Island, taken at the same time (Pl. XIV A, Fig. 5). The latter section is very interesting. It is in this region that the two branches, the North Cape Current and the Spitsbergen Current divide. There is much more water with salinities above 35·1 ‰ south of Stat. 66 (cf. the charts, Pl. III) than north of that station, where only a comparatively thin layer of it occurs between 50 and 100 metres. This layer is also seen in the transverse section farther north through Stat. 63 (Pl. XIV A, Fig. 4). The probable explanation is that Stats. 66 and 65 (between 72 and 73° N. Lat.) are just outside the Bear Island Channel (cf. Fig. 8), where a great volume of the Atlantic water runs eastwards along the southern side-slope of that Channel, having depths of more than 300 metres (cf. Pl. XIV A, Fig. 3). There is probably also a cyclonic vortex-movement in the deeper strata at the mouth of the channel (cf. NANSEN, 1906; see also our Pl. XIII, especially the charts for 200 and 300 metres), by which the waters of the deeper strata are much intermixed, as is also indicated by the lower salinities and temperatures north of Stat. 66, in our longitudinal section Fig. 5 (Pl. XIV A). The shape of the isopyknals in this section proves the correctness of our view. Their inclination south of Stat. 65 indicates that the movemeut of the upper water-strata as compared with that of the deeper strata, has had an eastward component; while the isopyknals north of 65 run practically horizontally, or the movement may possibly have had a small westward component.

We have no sections showing the further course of the current to the North of Bear Island, but it is known from other investigations that the current advances farther northward, giving off one or two westward branches, west of Spitsbergen, while the remainder turns sharply to the east, north of Spitsbergen, into the North Polar Basin [NANSEN 1906, HELLAND-HANSEN and KOEFOED 1909]. Some of our charts, however, representing the observations made by various sealers and whalers, show some interesting features in this connection (Pls. V, VI, IX, XII, XIII and Figs. in Chap. IX—XI). They show, with some variations, that a tongue of relatively salt surface-water extends westwards from the northern branch of the Current at about the latitudes of Bear Island (74°—76° N.). Another tongue, sets off westwards west of Spitsbergen, as already mentioned. These tongues show the existence of vortex-movements and cyclonic systems in the Greenland Sea similar to those found in the southern half of the Norwegian Sea. They will be discussed more fully in Chapter X.

Considering that the quantities of diluted Atlantic water carried out of the Norwegian Sea by the North Cape Current and the Spitsbergen Atlantic Current are smaller than the quantity of Atlantic water carried in, we must conclude that a part of the latter finds its way towards the East Greenland Polar Current inside the area of the Norwegian Sea, and flows out with this current through the Iceland-

Greenland Channel. This probably occurs only to a small extent between Jan Mayen and Iceland, it must chiefly be north of the latter. There may possibly be some westward flow of water in the region immediately south and north of Jan Mayen joining the intermediate layer of warmer water underlying the cold water of the Polar Current. The fact that the intermediate warm layer has a much greater extension in the region between Jan Mayen and Greenland (cf. Chap. IX) than farther north, might seem to indicate such an inflow of warmer water from the east in this region, where we have very few observations; but the probability is that at least the greater part of this intermediate warm water in the sea between Jan Mayen and Greenland comes from the north with the Polar Current along the Greenland continental slope, as will be mentioned in Chap. IX.

Another westward flow of the water from the Atlantic Current, is the above-mentioned westward current west of Spitsbergen and south of the Spitsbergen-Greenland Ridge (cf. Pl. XIII), which is the principal contributor to the intermediate warm water-layer (between the levels of 100 or 200 and 700 or 800 metres below the surface) underlying the East Greenland Polar Current, north of 73° or 74° N. Lat. (cf. Chap. IX & X). It is certainly only a very small portion of this intermediate warm water-stratum which comes from the North Polar Basin.

A small quantity of the Atlantic water with somewhat reduced salinities goes every winter to form the bottom-water in the central area of the great cyclonic vortex of the Northern Norwegian Sea; but this quantity is evidently so small that is is of little importance compared with the masses carried by the Norwegian Atlantic Current.

2. The Velocities of the Current, and the Volumes of Water Conveyed by it.

The only *direct current-measurements* hitherto made in the Norwegian Sea are those of July, 1906, referred to above on p. 106 *et seq.* [HELLAND-HANSEN, 1907]. The station on Storeggen (Stat. 307) was taken at a place where the salinity at the surface was 32·81 ‰ and at the bottom (260 metres) 35·28 ‰. Thus the upper layers consisted of coast-water, while the Atlantic water with salinities above 35·0 ‰ was found below 75 metres. The results of the observations will be seen from the following table, where the mean velocity and direction of the current are introduced together with the temperature, salinity and density:

Depth	Salinity	Temper.	σ_t	Current.			
				Mean Direction (true).	Mean Velocity.	Maximum Velocity.	Minimum Velocity.
m.	‰	° C.			cm./sec.	cm./sec.	cm./sec.
2	32·91	10·95	25·18	S. 48 ° W.	23·3	32·6	18·0
5	·89	·82	·185	S. 47 ° W.	25·9	35·6	12·1
10	·97	·12	·37	S. 47 ° W.	25·2	36·8	12·6
20	33·47	9·04	·93	S. 41 ° W.	17·2	40·0	4·4
30	34·04	6 4	26·76	S. 55 ° W.	14·9	31·9	3·4
50	·44	·53	27·065	S. 60 ° W.	11·9	26·6	2·5
100	35·10	·44	·60	S. 48 ° W.	11·9	25·3	4·9
200	·24	·61	·675	S. 49 ° W.	14·8	28·0	5·8

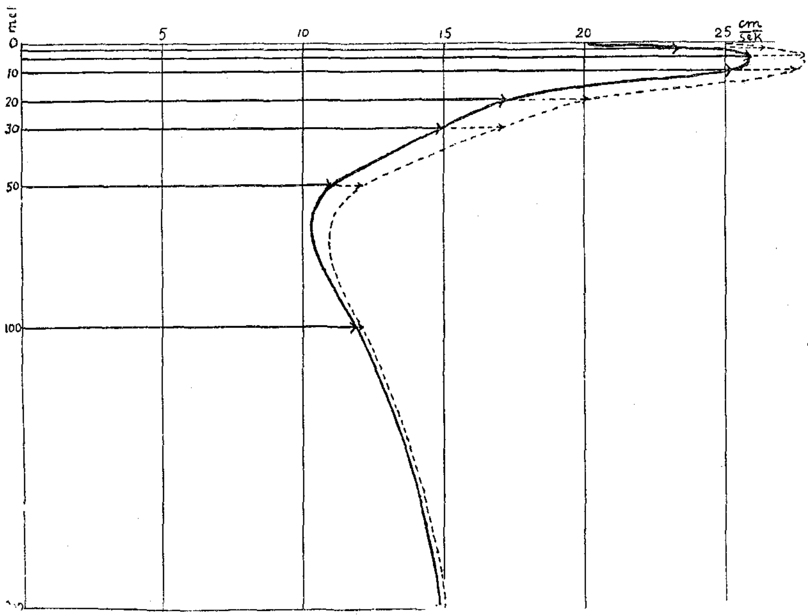


Fig. 40. Average Velocity of Current at Storeggen, July 12, 1906. [HELLAND-HANSEN, 1907a, Fig. 4.]

The mean velocities are represented by the diagram in Fig. 40. The unbroken line shows the average velocities calculated on the basis of progressive vector diagrams. It shows the average amount of water

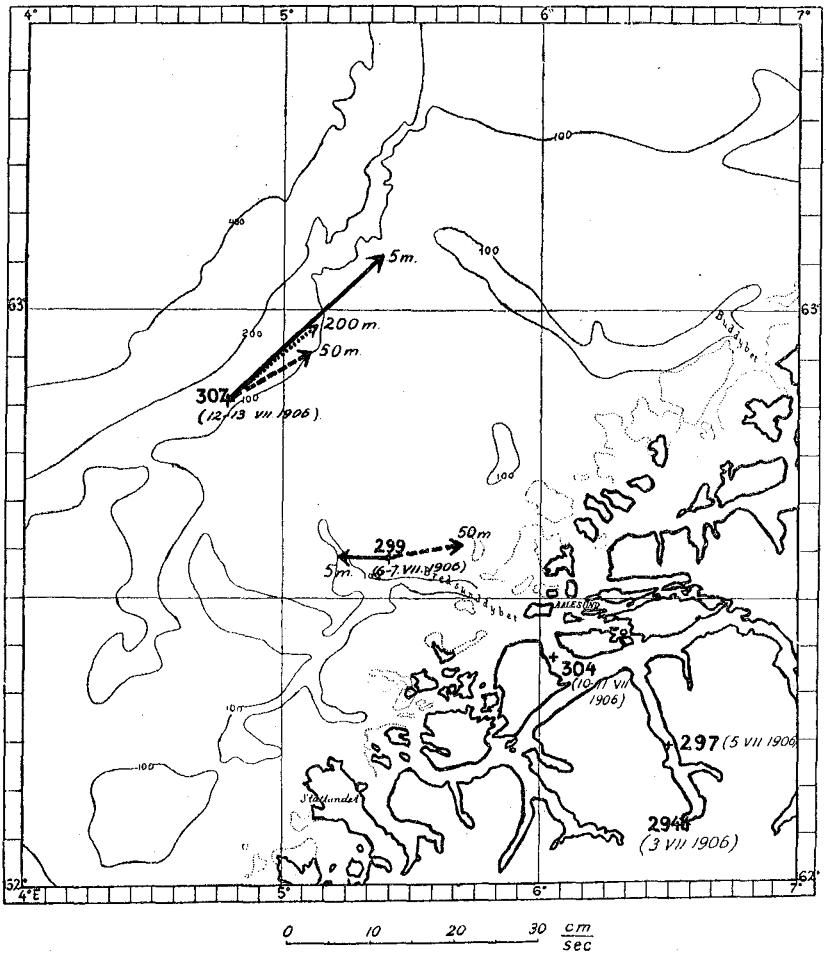


Fig. 41. Stations off Söndmöre, July, 1906. Arrows indicate the velocity and direction of the current, at 5, 50 and 200 metres. [HELLAND-HANSEN, 1907 a, Fig. 1.]

conveyed in 25 hours (two tidal periods), calculated in a straight line from the point of departure along the mean direction of the current, these values having been introduced in the table above. The broken-lined curve gives the mean magnitude of the movements without consideration of the changes in direction. The difference between the two curves is greatest in the upper layers, where the changes in direction are more striking than in the deeper-lying Atlantic water. Fig. 41 shows the position of the Station. The arrows indicate the mean velocity and direction of the current in 5, 50, and 200 metres. It will be seen that the current on an average runs parallel with the continental slope.

The observations show a minimum average velocity near the boundary between the top-layer of coast-water and the underlying Atlantic water, at about 70 metres below the surface. The velocities in the deeper strata, with salinities above 35 ‰, had an intermediate maximum; the *mean* velocity was greater at 200 metres than at 100 metres. The direction varied but little, and least in the deeper layers; whereas the velocity changed very much, most in the intermediate layers above the Atlantic water. But even in the deepest strata great variations were observed, *e. g.* at 200 metres between 28·0 and 5·8 cm./sec. Five measurements in 250 metres gave 21·5, 19·8, 5·9, 7·3, and 7·5 centimetres per second. The latter level (250 metres) was only some few metres above the bottom, but nevertheless velocities as great as 21·5 cm./sec. (10 naut. miles in 24 hours) were observed. This velocity is so great that the water would move grains of sand, and wash them away from the bottom, which at this place was rocky.

We have shown above, on p. 108 *et seq.*, that the variations in the current at 10 metres might be the combined result of some kind of pulsation in the ordinary current, and the variations in the tidal currents. The conditions at 100 metres were more complicated, but it seemed probable that similar pulsations also existed at this depth. However this may be, these measurements show quite clearly that the Atlantic Current may change rapidly and does not flow with a constant speed, not even for so short a time as a few hours.

We have made a good many attempts to *calculate the velocities* by means of BJERKNES's theory [see SANDSTRÖM and HELLAND-HANSEN, 1903].

According to BJERKNES, the acceleration of the circulation is

$$\frac{dC}{dt} = -\int v dp - 2\,\omega \frac{dS}{dt} - R$$

Let us suppose that we have a closed curve of water-particles. The sum of all the tangential components along this curve is called the "circulation" of the curve (Lord KELVIN'S definition). In BJERKNES'S formula, v is the specific volume, dp the differential of pressure, ω the angular velocity of the Earth, S the area of the projection of the curve on the Equator and, accordingly $\frac{dS}{dt}$ the variation of this area with time, while R indicates the effect of the friction. If the curve be composed of the vertical lines at two stations, and two horizontal lines between these stations, one at the surface and the other at a given depth, we may calculate the diference of the mean velocity at the surface and at the given depth, according to the formula

$$c_0 - c_1 = \frac{A - R}{2\ \omega\ 10^5\ l \sin \lambda},$$

where c_0 and c_1 are the components of the average velocities at the surface and at the given depth respectively, the components being reckoned at right angles to the direction of the section; A represents the integral to the right in BJERKNES's formula, the numerical values being found by means of Sandstrøm's and Helland-Hansen's Tables [1903]. l is the distance between the stations in kilometres, and λ the Latitude. [HELLAND-HANSEN, 1905 a].

This latter formula applies to stable conditions only. It is then supposed that the distribution of pressure and specific volume (or density) is regulated by the velocity in such a manner that the forces due to this distribution are equal in magnitude, but opposite in direction to the forces due to the rotation of the Earth, friction being not taken into account. The formula is thus independent of the causes of the oceanic currents, and gives only the relation between the velocities at different depths, whatever those causes, and whatever the distribution of temperature and salinity may be; but it will not give trustworthy results if stable conditions have not been reached, or if the distribution of pressure and specific volume be rapidly changed, for instance by boundary-waves. Such waves would give the water-layers oscillatory movements, and raise or lower the isosteres at comparatively short intervals of time. The calculation can then only be satisfactorily made if the observations of temperature and salinity are taken in the same phase of the wave-motion at the various stations, *e. g.* when the crest of the wave has been observed at the stations that are to be compared. Suppose, for instance, that we have two stations, O and P, with a well-defined slope of the isosteres downwards from O to P, if no boundary-waves exist. In the case of boundary-waves we may perhaps observe the trough of the wave at O and the crest at P, and the course of the isosteres will be horizontal or even slope downwards from P to O. The real differences of the mean velocities could then only be calculated if the phase and amplitude of the wave at each station were known.

We have shown in Chap. VI that the current-measurements seem to indicate the existence of pulsations, causing great variations in the velocity. We have not sufficient material to settle the very important question as to whether the isopyknals (isosteres) will follow these variations so quickly that the distribution of density at any time will correspond to the actual current, or more or less to its average velocity. In the former case, these pulsations will cause another difficulty in the calculation of the current, similar to that due to subsurface waves. It will in any case be of vital importance in the hydro-dynamical study of the great ocean-currents to have these phenomena investigated; and until this is done, it will be very difficult to obtain reliable results by calculations.

In order to calculate the differences of velocity exactly it would also be necessary to know the influence, R, of friction. As we do not yet know this factor, and assuming that it is small compared with A, it has been ignored in our calculations which in any case are only rough approximations.

The difference, $c_0 - c_1$, in the second formula is the mean difference of the components reckoned at right angles to the direction of the section, as previously mentioned. If the velocity at a certain depth is *nil* the component will also be *nil* ($c_1 = o$) and the component (c_0) of the surface-velocity will be found at once. If the direction of the current forms an angle of α° with the sectional plane, the real velocity at the surface will be $v_0 = \frac{c_0}{\sin \alpha}$.

The calculated mean differences of velocity between the surface and the different depths (between two stations) from which observations are made, may be plotted out on millimetre-paper, the differences along the axis of abscissæ, and the depths as ordinates. If the velocity at a certain depth below the surface, be regarded as *nil*, the ordinate corresponding to this point of the curve, will make the vertical O-line (the axis of ordinates), and the components of velocity at different depths nearer to the surface, will be found directly from the curve.

The volume of water flowing through a section may be found by means of such curves. The area enclosed by the curve, the axis of abscissæ and the axis of ordinates will represent a certain number of square metres. This number, multiplied by the distance between the stations, in metres, will give the volume of water flowing through the section, in cubic metres per second. The value found in this way will be independent of the angle between the direction of the section and that of the current, because, in order to find the area of the true transverse section (at right angle to the direction of the current), we should have to multiply the section in question by the very factor (sin α) by which the velocity component would have to be divided in order to find the true velocity of the current.

The calculations of the average velocities by means of BJERKNES's theory will generally give too low values. This is to some extent due to the fact that the influence of friction has not been taken into account when using the formula for numerical investigations. The average velocities found between stations not far apart, often show, however, very high values, whereas when the distance beween the stations is great, they are as a rule very small. This is easily accounted for if we suppose that vortex-movements occur between the stations; the waters in the section are then moving in different directions, and the mean velocity in one direction at right angles to the sectional line will thus be only small, even if the movements are considerable at each single point.

Figs. 42—44 represent three dynamical sections, Fig. 42 taken in May, 1901 (off Feie, corresponding to Figs. 1 and 2, Pl. XVI), Fig. 43 in May, 1904 (off Feie, cf. Pl. XXIV A, Fig. 1), and Fig. 44 in June, 1904 (off Stad, cf. Pl. XXIV A, Fig. 2). The small numbers (to the right of the vertical lines in Fig. 42 and to the left in

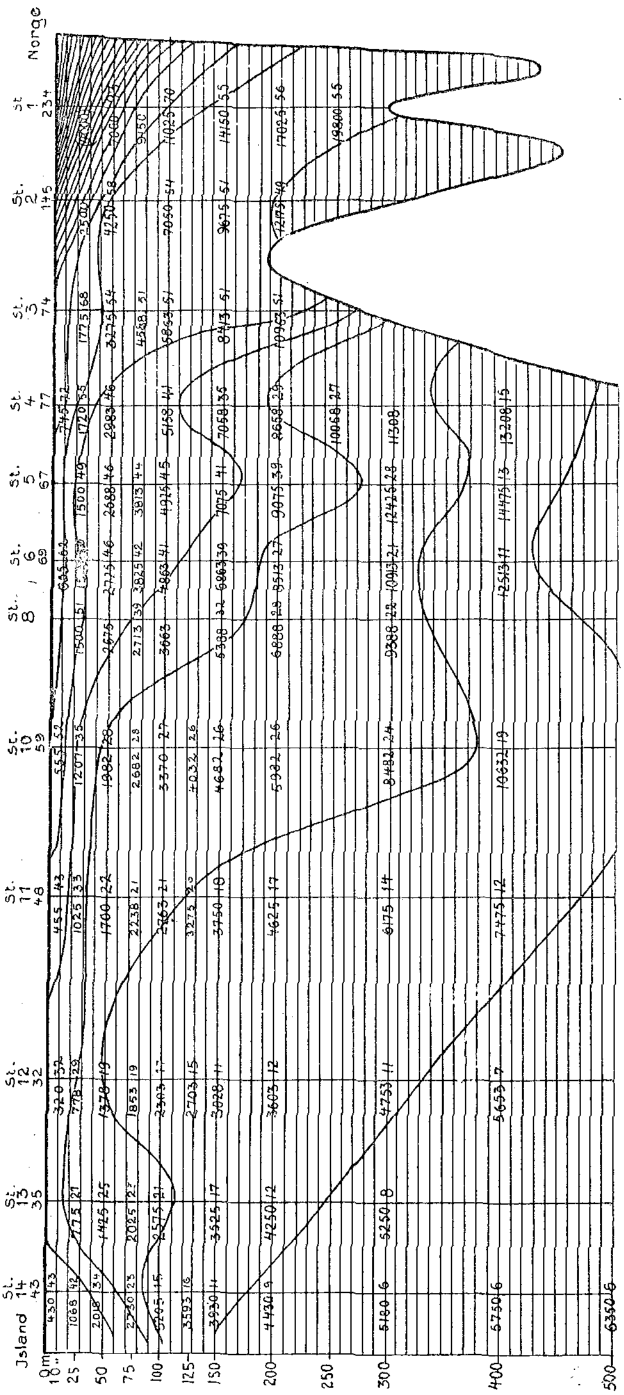


Fig. 42. Dynamical Section seawards from Feje, May, 1901 [SANDSTRÖM and HELLAND-HANSEN, 1903, Fig. 4].

the other two) are figures corresponding to the values of specific volume, and the large numbers are numerical expressions of A ($-\int vdp$) for the vertical line from the surface down to various depths. The curves are lines of equal values of specific volume (isosteres); and the *inclination* and number of these curves, as also the differences in the numerical values of A in a horizontal direction, indicate the values of the gradients (1). The curves in the charts, Figs. 45 and 46, from 100 and 200 metres below the *surface, in May*—June, 1904, are lines of equal values of that part of A which is found from the surface down to 100 and 200 metres at

(1) The isosteres are not drawn for the upper strata to the right in Figs. 43 and 44, near the Norwegian coast, as they would have been so numerous that they would have made the sections quite black.

the various stations. These curves indicate approximately the direction of the currents; the closer these lines are crowded together, the greater are the differences of velocity between the surface and 100 or 200

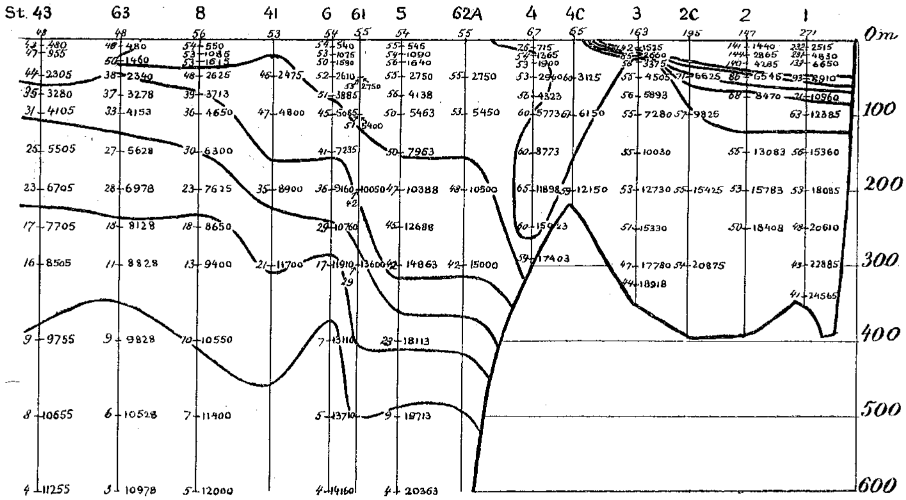


Fig. 43. Dynamical Section seawards from Feje, May, 1904.

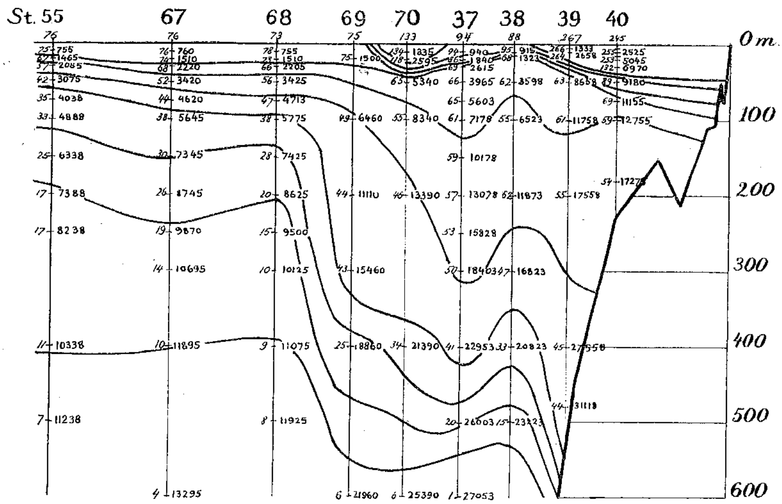


Fig. 44. Dynamical Section seawards from Stad, June, 1904.

metres. The curves have not been drawn between the Færoes and Iceland, nor in the Færoe-Shetland Channel; they would have run close together in these areas, indicating great velocities. These diagrams show that the current in May—June, 1904, flowed along the conti-

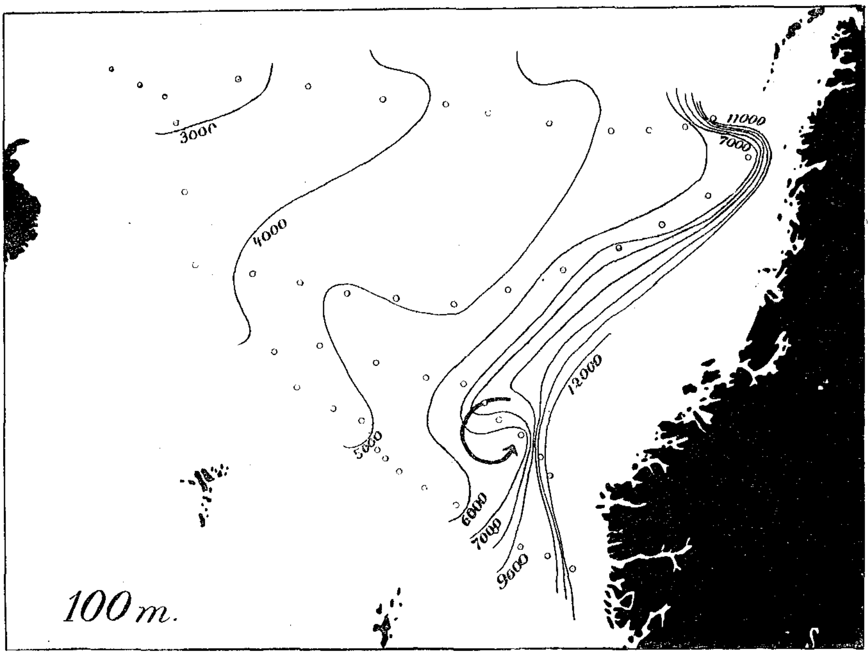


Fig. 45. Dynamical Chart for the upper 100 Metres, May—June, 1904.

nental slope, with great velocities off Stad and off the Lofoten Bank, and with reduced velocities off Helgeland. The curves make some bends. That to the north-west of Stad is especially conspicuous, corresponding to one of the vortices mentioned above (cf. Fig. 37). Another, west of Lofoten (Fig. 46), corresponds to the northern part of the cyclonic movement of the southern Norwegian Sea.

The calculations give the following surface-velocities of the current in the eastern part of the Færoe-Shetland Channel, as based upon the Scottish observations [Helland-Hansen, 1905 a, b; Robertson, 1905, 1907]:

	1902	1903		1904	
	August	May	August	May	August
Centimetres per Second	20	30	20	30	20
Naut. Miles per 24 Hours	9	14	9	14	9

In June, 1904, the velocity seems to have been about 12 nautical miles in 24 hours. The number of reliable observations from

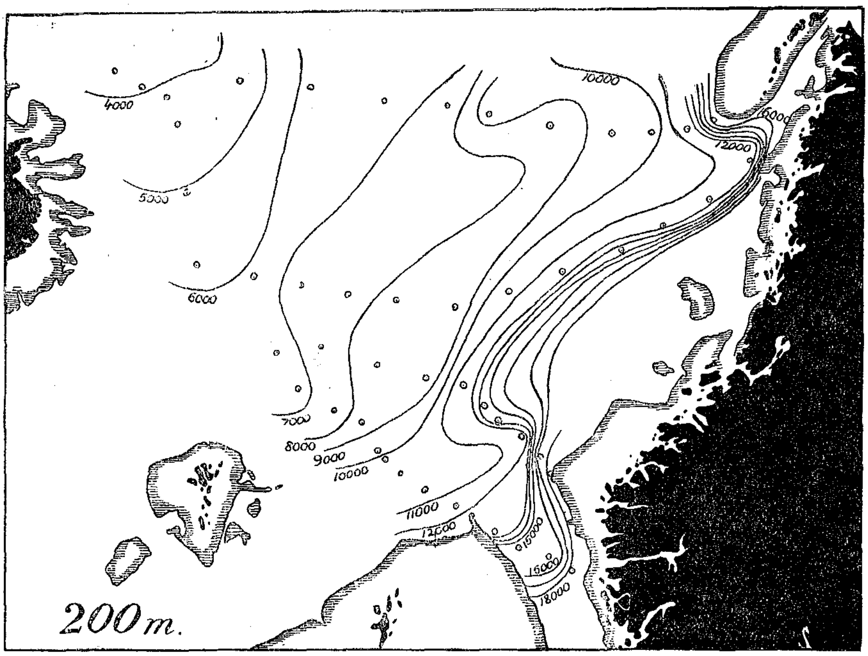


Fig. 46. Dynamical Chart for the upper 200 Metres, May—June, 1904.

other seasons is insufficient; but some observations from December, 1902, seem to indicate that the current then moved with less speed than in August of the same year.

These calculations agree very well with each other, indicating a surface-velocity of about 30 cm./sec. in May in two different years, and about 20 cm./sec. in August in three different years. They seem to show a maximum velocity of the current in spring and a minimum velocity in autumn.

The values given in the above Table have reference to the waters near the edge of the continental slope off the Shetlands. The velocities are less over the shallow parts of the continental shelf, as also farther west, in the central part of the channel. In the latter locality the calculations in some instances (*e. g.* in May, 1904) give great southward velocities, which are evidently due to the formation of vortices, as mentioned above. In May, 1904, the water at the surface between Stations Sc. 19 A and Sc. 19 B seemed to move southwards at the rate of about 25 cm./sec. or nearly as much as the velocity northwards between Sc. 19 B and Sc. 20.

GEHRKE [1907] has tried to calculate the velocity of the current in a section from Scotland towards the northwest. He has based his calculations upon the hydrographical theorem of KNUDSEN [1900], and has found the mean velocity of the current over the continental shelf to be 9·4 cm./sec., or 4·4 $\frac{\text{miles}}{\text{24 hours}}$. This value is less than that found by BJERKNES's theory; the reason perhaps being that GEHRKE's section included the waters close to the shore, where the velocities are reduced.

In the main part of the current, by the continental slope off the Shetlands, the velocities seem to be almost as great at 100 or 200 metres below the surface as at the surface itself. The maximum velocity is sometimes even found at intermediate depths, as for instance in August, 1902, at about 40 metres, and in December, 1902, at about 100 metres. From, say, 300 metres and downwards, the velocity decreases rather rapidly until zero is reached, generally somewhere between 500 and 700 metres, or even deeper. The bottom-water has apparently a movement southwards, sometimes with a velocity of several centimetres per second [HELLAND-HANSEN, 1905 a, p. 10].

We have already mentioned that the main part of the current in the Norwegian Sea, moves along the continental slope of the coast of Norway. In order, therefore, to find the velocities of this current, it is of great importance that stations should be taken as close together as possible, from the edge of the continental shelf seawards. We have unfortunately not made sufficient observations of this kind on most of our cruises, and have therefore only imperfect material for the calculation of the velocity along the slope.

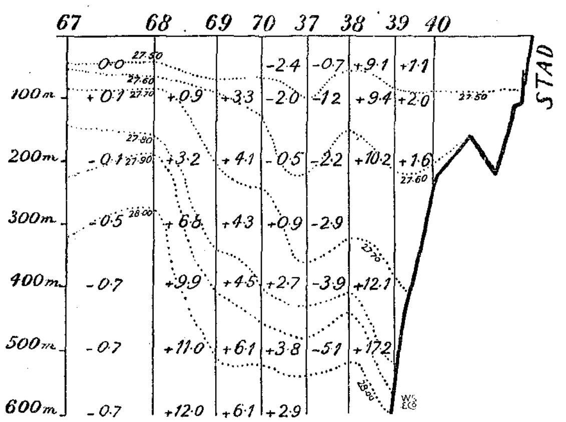


Fig. 47. Section seawards from Stad, June, 1904, giving the differences, in cm. per second, between the velocity-components at the surface and at the various depths down to 600 metres. The dotted lines are the isopyknals of 27·50—28·00.

Fig. 47 shows the differences of the velocity-components as calculated for the section seawards from Stad, June, 1904 (Pl. XXIVA, Fig. 2). The numbers give the differences between the components at the surface and those at various depths; + *indicates that the direction of the surface-component* was north or north-east (at right angles to the sectional plane) in relation to the component at the depth in question; — indicates the reverse relation between the components (cf. Fig. 34).

At the edge of the continental slope, between Stations 39 and 40, the differences are very small. They indicate a minimum of velocity towards the north-east, at a depth of about 100 metres below the surface. The boundary between the upper layer of coast-water and the deeper layer of Atlantic water was found just at this depth, at Stat. 40. It was stated above (p. 155) that the current-measurements on Storeggen demonstrated a minimum of velocity at about 70 metres, just at the level of the isohaline of 35 ‰. These measurements are so far quite in accordance with our calculations. Similar conditions have been found by means of calculations in many other cases; and we may therefore conclude that the current over the outer part of the continental shelf generally has a minimum of velocity at some intermediate level near the boundary between the coast-water and the Atlantic water. Thus the upper layers of the Atlantic water moving over the continental shelf, seem to flow with less velocity than the deeper strata.

Over the continental slope, between Stations 38 and 39, the differences of the velocity-components are rather great. The distribution of salinity and temperature indicates that the direction of the current at this place was very nearly at right angle to the sectional plane, *i. e.* the differences mean the differences of velocity and not only of the components. The comparatively high salinity (35·075) and temperature (5·23° C.) at 480 metres, Stat. 39 (cf. Pl. XXIV A, Fig. 2), indicate that the current at this depth was moving north-eastwards with considerable velocity. The velocity probably amounted to several centimetres per second, even at 600 metres. The calculation would then give a surface-velocity of more then 20 cm./sec., the velocity at 100 metres being between 10 and 15 cm./sec., after which it decreased very slowly downwards to 400 metres, and then more quickly. These values seem to agree very well with the velocities measured in the

Atlantic water on Storeggen (at 100 metres, 11·9 cm./sec.; at 200 metres, 14·8 cm./sec.).

The differences calculated for the waters between Stations 37 and 38 show that the movement of the surface-layer had a component towards the south-west in relation to the deeper strata. If the water at the surface had had a movement towards the north-east, the movement in the same direction at 500 metres must have been considerably greater (by more than 5 cm./sec.). Between the next two Stations, 37 and 70, the movement northwards was greater at the surface than at 500 metres, but still greater at 50 and 100 metres, and even at 200 metres. Farther seawards the differences are greater, especially between Stations 68 and 69 ($c_0 - c_{500} = 11$ cm./sec.). Between Stats. 67 and 68, where only a small volume of Atlantic water was found in the upper layers (down to about 100 metres), the differences are quite insignificant. The waters in this locality moved probably more along the section than across it.

By these calculations, we can only find the real velocity, or the differences of velocity, in cases where the directions are known. But we do not know the directions with sufficient certainty in detail, on account of the lack of observations. A great many observations would be necessary for this purpose, as was pointed out above; so that even the relatively large number of stations from May & June, 1906, does not suffice. One of the chief difficulties in the study of the mean direction will be caused by vortex-movements, such as we have frequently mentioned, more especially as the diameter of the the vortices often seems to be rather small.

When calculating the differences of the components of velocity, we have assumed that the conditions have been stable $\left(\frac{dC}{dt} = 0\right.$ in BJERKNES's formula), that is to say that the wave-like bends of the isopyknals have not been caused by progressive sub-surface waves, or similar phenomena, which temporarily disturb the hydrostatic equilibrium. According to our view, we have had such disturbances in some cases, and it will be impossible by means of calculations to arrive at exact conclusions as to the velocity of the current until these disturbances are known. The distribution of salinity, temperature, and density, in the Stad section of June, 1904, may be explained in both ways, namely, by vortex-movements, and by oscillatory movements caused by progressive sub-surface waves. We have already stated that we consider the first explanation to be the more probable one in this case. If this assumption holds good, our calculations (as introduced in Fig. 47) demonstrate numerically a vortex with its vertical axis at about Stat. 38. The waters east of this station were moving towards the north-east with a surface-velocity of more than 20 cm./sec.; part of this water has afterwards passed the section once more with a component towards the south-west, between Stations 37 and 38. Unfortunately, we cannot decide from our material, whether this motion has gradually been turned into one towards the south-east and east so as to join the main body of the current again, or towards the west and north-west so as to carry the waters northwards again, farther seawards.

However this may be, it seems quite certain that the velocities of the Atlantic water differ very much in different bands lying side by side. These differences of velocity will in most cases cause the formation of vortices. The differences themselves may be due to various influences, such as topographical conditions, or the encountering of other currents at the sides, or atmospheric conditions. The vortices may be more or less stationary, *i. e.* they will be formed in a certain locality without being carried away from it. If such a vortex is formed within the area of a current and not at its outer boundaries, it will be only partial. In the case mentioned above (with an axis at Stat. 38) it means that the waters, after having turned southwards, proceed farther towards the west and not towards the east. But if the vortex is carried away by the general drift of the waters, it may be complete (*i. e.* circular); the result will then be that the waters are very much intermixed. It is probable that vortices of both kinds exist in the Atlantic current.

If we now calculate the mean differences of the velocity-components for the whole section of the Atlantic Current, we shall find relatively small values. We have, for instance, for the whole Stad section, of June, 1904, between Stations 39 and 68,

between the surface and

10	50	100	200	300	400	500 metres.
0·6	1·7	2·0	3·0	4·1	5·5	6·9 cm./sec.

As the average direction of the current seems, upon the whole, to be at a right angle to the section, and as the waters at 500 metres probably have a movement almost in the same direction, the conclusion to be drawn is that the average surface-velocity between these Stations has been greater than 7 cm./sec. (a little more than 3 miles in 24 hours). The surface-layer consists, for the greater part, of water with salinities below 35 ‰. In the Atlantic water at 100 metres, the average velocity would be at least 5 cm./sec. ($2^1/_2$ miles in 24 hours), but at 300—400 metres, for instance, only 2—3 cm./sec. (about 1 mile in 24 hours).

The section seawards from Stad, of June, 1903, shows a very regular distribution of salinity and temperature, and consequently a very regular shape of the equilines (see Pl. XXI A, Fig. 2). We find therefore almost the same differences between the velocity-components for different parts of the section. The calculations give the following differences:

	Between the surface and					
	100	200	300	400	600	metres.
Between Stats. 32 and 33	0·4	1·0	1·7	2·6	5·3	cm./sec.
— — 30 » 33	0·6	1·3	2·3	3·2	5·1	—

The first two Stations, 32 and 33, include that part of the current which is nearest to the continental slope, while the others (30 to 33) include the whole section of Atlantic water. The differences found are much the same; the equality proves that the Atlantic water moved with almost the same component of velocity towards the north-east in all parts of the section. We had not then such differences of velocity as were found in June, 1904; and consequently the distribution of salinity and temperature indicates no vortices, though they might perhaps have been found if more observations had been taken. It is thus very characteristic that the 35-isohaline in the section from 1903 is almost identical with that in the section of June, 1904, represented in Fig. 38, B, where every second station has been left out. In the latter section, however, the 35·2-isohaline exhibits a wave-like bend which is totally absent in the former section, and it is not improbable that in reality, the vortices did not exist in June, 1903, to the extent in which they occurred in the same month of the following year. This may be due to the fact that the section of 1903 was taken farther to the north than that of 1904. And it will be seen in the charts in Fig. 37, that no vortices have been indicated along the line that corresponds to the section of the former year.

The mean differences of the velocity-components of the section, taken as a whole, were greater in 1904 than in 1903. This is probably to some extent due to the fact that the differences of 1904 included waters with great velocities nearer to the continental shelf than was the case with those of 1903. Within the Atlantic water, however, (*e. g.* at 100 and 200 metres) the average velocities seem to have been much the same, while the surface-layer in 1904 consisted chiefly of water with less salinity than 35 $^0/_{00}$, and comparatively great velocities.

In November, 1903, a section (Pl. XXIII, Fig. 3) was taken almost along the same line as the Stad section of June, 1903. The isopyknals in the November section show only indistinctly the wave-like bends, and the vortices have consequently been of little importance. The calculations show that the maximum velocity of the current was then found farther seawards (comparatively far from the continental slope) than is generally the case. The greatest differences of the velocity-components were found between the Stations 51 and 32, *viz*:

Between the surface and

100	200	300	400	metres.
1·2	3·6	7·9	13·1	cm./sec.

We have unfortunately no observations from the deeper strata.

For the whole section, between Stations 33 and 52, we get the following differences in the velocity-components:

Between the surface and

50	100	150	200	300	400	metres.
0·3	0·5	1·0	1·6	3·0	4·4	cm./sec.

These values are somewhat greater than the corresponding values of June, 1903, and agree very well with the differences in the Atlantic water below the surface in June, 1904.

As a result of these investigations we may conclude that the surface-current off the continental slope west of Söndmöre has an average velocity of between 6 and 10 cm./sec. (3—5 miles in 24 hours). The velocity generally decreases downwards, slowly, however, in the upper layers. Near the slope, the current runs as a rule faster, with velocities up to more than 20 cm./sec. (9 miles in 24 hours).

The sections off Helgeland, of June, 1903 (Pl. XXI A, Fig. 3), and June, 1904 (Pl. XXIV A, Fig. 3), cut the current obliquely. They both show a very regular distribution of salinity and temperature, without indications of vortices (or of subsurface waves). The maximum velocity is found near the surface above the continental shelf, as in most other cases.

The differences of the velocity-components in the section seawards from Lofoten, of May, 1904, are seen in Fig. 34, which has been drawn in the same manner as Fig. 47. It illustrates the vortices very clearly, with southward movements between Stations 22 and 23 A, and between 20 B and 21 A. The differences of the velocity-components found near the continental slope (Stats. 23—23 A) are exactly the same as those found near the western boundary of the Atlantic water (Stats. 20 B—20 A). The velocities near the slope seem to be smaller than in the sections farther south. The mean differences of the velocity-components for the whole section of the Atlantic water, from Stat. 23 A to Stat. 20 A, are as follows:

Between the surface and

100	200	300	400	500	600	metres.
0·3	0·5	0·9	1·3	1·3	1·2	cm./sec.

The average surface-velocity over the whole area of the Atlantic Current seems thus to be considerably less off Lofoten than off Söndmöre. In all probability it does not amount to more than a few centimetres per second. This agrees very well with the results of the dead-reckonings of the ships, no appreciable deviation from the courses, given by the reckonings, having been found in this part of the sea, provided that the weather has been calm. In many parts of this area, however, the velocities may be rather great, as for instance near the western boundary of the Atlantic water (more than 10 cm./sec., or 5 miles in 24 hours). But the deviation in the ship's course in these localities, will be almost counterbalanced by the opposite drift in other places, where the waters move southwards.

In February, 1901, some stations were taken seawards from Vesteraalen (Pl. XV, Fig. 2). Stat. 14 was situated close to the continental slope, and Stat. 15 about 45 kilometres farther seawards (to WNW.). The isopyknals (or isosteres) slope here very much, and the differences of the velocity-components have consequently been found to be very great (northwards at the surface). They are,

between the surface and

50	100	200	300	400	500	600	700	800	900 metres.
4·1	7·3	12·1	15·9	19·8	23·0	25·9	28·8	31·9	34·7 cm./sec.

This means a surface-current along the continental slope of at least 35 cm./sec. (17 miles in 24 hours) or much more than along the slope farther to the south, off the southern islands of the Lofoten group. It is well known that the surface-current at the place in question, may often be very strong, and this consequently agrees very well with our calculations. The weather, however, was very stormy when Stations 14 and 15 were taken, and it may be, therefore, that the stable conditions, presupposed by our calculations, had not been attained.

By means of the Scottish observations in the Færoe-Shetland Channel, of August, 1902, Helland-Hansen [1905, a, b] found *the volume of water* carried northwards through the Channel by the Norwegian Atlantic current to be about 4 million cubic metres per second, or 125,000 cubic kilometres per year. The calculation was made in the manner already described.(1)

We have tried to make several calculations of this kind. They agree very well with each other, but do not claim to be absolutely trustworthy.

The observations of May & June, 1904, give the following volumes of water conveyed by the Norwegian Atlantic current:

In the Færoe-Shetland Channel, about 4·5 million cub. m./sec. (140 000 cub. km./year).

Through the section seawards from Stad, 3·8 million cub. m./sec., almost half of which passed close to the continental slope, between Stations 38 and 39.

Through the Lofoten Section, seawards to Stat. 20 A, in the upper 500 metres, 2·3 million cub. m./sec., more than half of it passing along the continental slope.

(1) A calculation by GEHRKE [1907] of the waters between the northern coast of Scotland and the upper part of the continental slope gave 1·9 million cubic metres per second. His calculation was made by an entirely different method (see above p. 162).

In May & June, 1903, we find:

Through the section seawards from Stad, about 4 million cub. m./sec.

Through the Lofoten Section, seawards to Stat. 19, in the upper 500 metres, 2·7 million cub. m./sec.

These figures indicate a decreasing quantity of Atlantic water northwards; and it seems very probable that such a diminution really takes place. Through intermixing processes much Atlantic water is transformed, partly by mixing with coast water and Arctic water at the sides, and partly by mixing with the underlying bottom-water. In this manner much of the northward-flowing Atlantic water will apparently disappear. It will be carried away, to some extent towards the west, and will not occur in the northern section, but will probably to a great extent form an integral part of other currents. We may say that probably between 4 and 5 million cubic metres of Atlantic water are poured every second into the Norwegian Sea through the Færoe-Shetland Channel, or between 125 000 and 160 000 cubic kilometres in the course of the year; and between 2 and 3 million cubic metres of water with Atlantic characters passes every second from the south to the north of the 67th parallel of Latitude (or 60 000 to 90 000 cubic kilometres a year).

We have estimated the total volume of the Norwegian Sea at about 4·12 million cubic kilometres. Only about $\frac{1}{30}$ of this volume will be made up in the course of one year by the waters of the Norwegian Atlantic Current, or in other words, this Current would take about 30 years to fill the sea-basin. The Norwegian Atlantic current is thus very small indeed in proportion to the Norwegian Sea basin. Our charts and sections of the Norwegian Sea show, however, that the masses of Atlantic water found there are very considerable. The fact seems to be on the one hand that these masses are renewed comparatively slowly, and on the other hand that the current, on account of vortex-movements, runs backwards and forwards, with a zig-zag motion, so to speak, through the sections, thus occupying a much greater part of the basin than it would have done if the movement had followed a straight course.

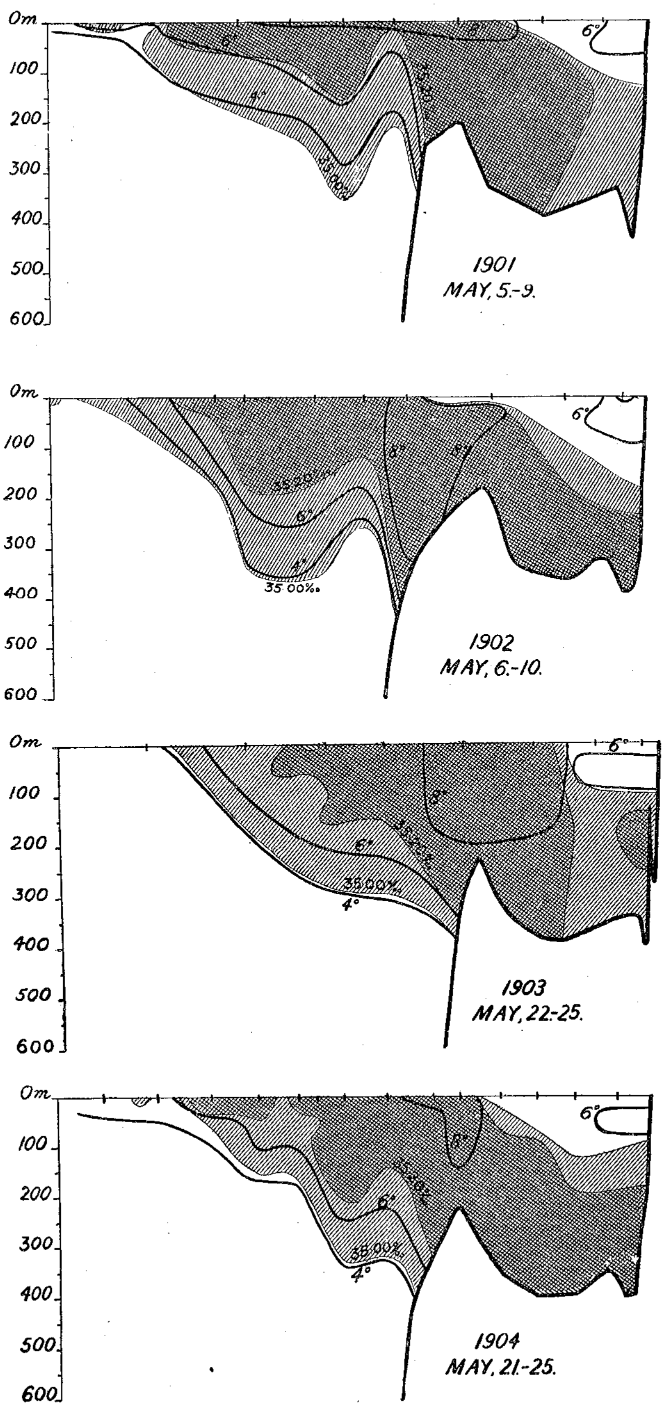
3. Annual and Seasonal Variations.

We have previously, on various occasions, mentioned that a study of the variations of the oceanographic conditions, based upon our observation-material, is connected with great difficulties, chiefly on account of certain general phenomena, such as great vortex-movements and subsurface-waves, with which we are insufficiently acquainted, but also because the observations taken at the various seasons of the year have been insufficient. A discussion of the variations in the intensity of the current will not therefore lead to so conclusive results as might be desirable, but a discussion of the variations in its temperature may, however, lead to very important results.

1. The Annual Variations.

May is the only season for which a fairly complete observation-material has been collected in different years, and a study of the annual variations must therefore be limited to this month. In the following figures, 48—51, we have reproduced from our plates parts of the sections running seawards from the Sognefjord. In these text-figures we have drawn the isotherms of 4°, 6°, and 8° Centigrade, and the isohalines of 35·00 and 35·20 ‰. The waters with salinities between 35·0 and 35·2 ‰ are marked by single hatching, and those with salinities above 35·2 ‰ by cross-hatching; the stations are indicated by marks on the surface-line. The date of the observations is not the same in all the four years; in 1901 and 1902 they were made between the 5th and 10th of May, and in 1903 and 1904 a fortnight later, between the 21st and 25th. Nor do the sections follow exactly the same line, as will be seen, for instance, from the differences in the bottom-line; the differences in this respect are, however, comparatively slight (cf. Pl. II). But even if they are taken into account, we shall nevertheless find considerable variations from one year to another.

Owing to what has been said above about the irregularities in sections caused by vortex-movements, subsurface-waves, etc. (Chap. VI), it is naturally very difficult to determine the quantity of Atlantic water actually occurring in a section, or rather running through the



Figs. 48—51. Sections seawards from Feje (Sognefjord), May, 1901—1904.

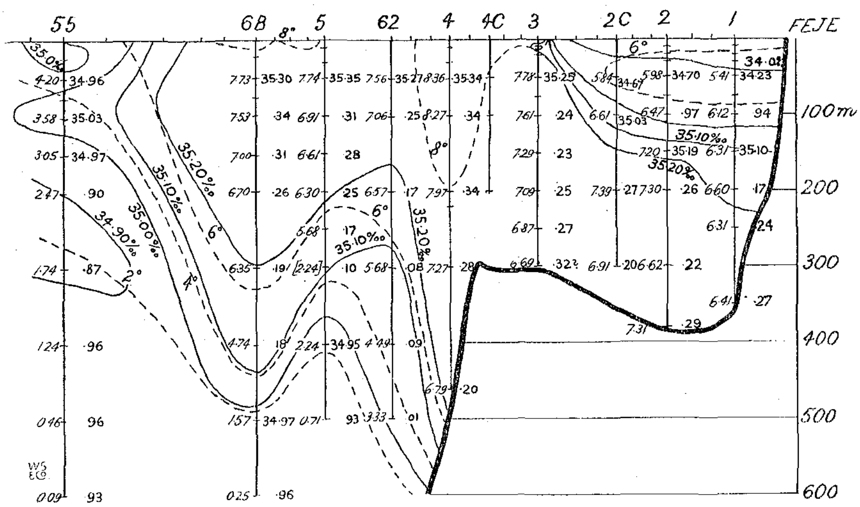


Fig. 52. Section seawards from Feje (Sognefjord), May 15—18, 1905.

section. But if we take the isohaline of 35·0 ‰ as the boundary line of the Atlantic water, and assume that the sections give fairly trustworthy representations of its shape, Figs. 48—51 show that this boundary line of the Atlantic water in the Sognefjord section enclosed different areas in the four years. The following areas have been found by planimeter:

Area (in square kilometres) of Atlantic Water in the Sognefjord Section, in May.

Year.	W. of Stat. 3.	E. of Stat. 3.	Total.
1901	84 sq. km.	64 sq. km.	148 sq. km.
1902	112 —	43 —	155 —
1903	107 —	42 —	149 —
1904	87 —	41 —	135 —
1905	138 —	46 —	184 —

We have, in these measurements, included the section from May, 1905 (see Fig. 52). Stat. 3 is situated near Tampen, not far from the continental slope; the second column gives the area of Atlantic water west of this station, and the third column the corresponding value reckoned eastwards from Stat. 3. The total area, as well as the part of it to the west of Stat. 3, was especially great in 1905.

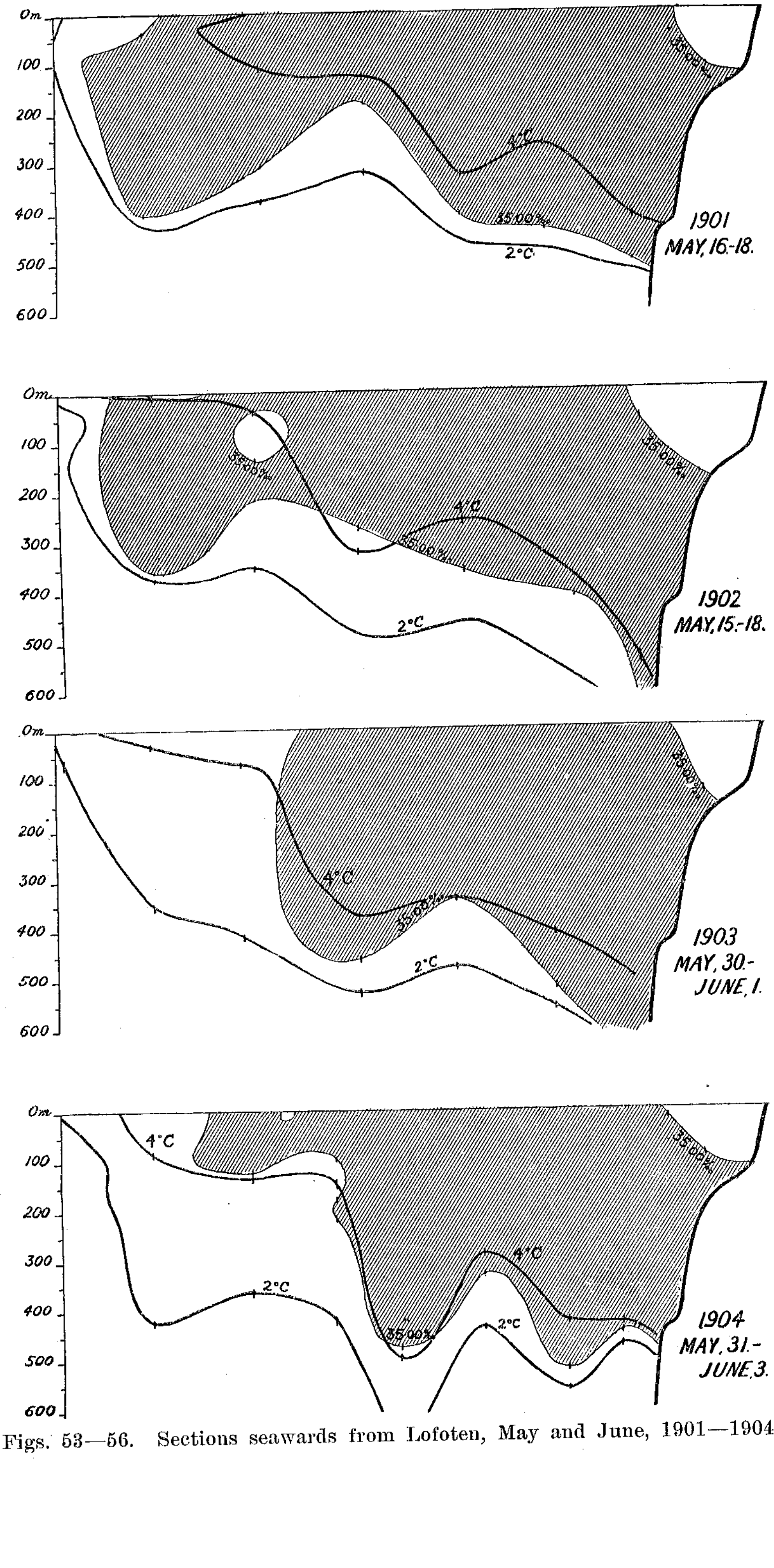
The isotherm of 8° C. encloses very different areas in the four sections. In 1901 this isotherm was found as an almost horizontal line just below the surface, showing that the heating of the surface-layer from above had commenced; while the temperature of the intermediate strata was everywhere lower than 8° C. Just the reverse was the case in 1902, when only a narrow part of the surface had temperatures above 8° C., while great masses of water at intermediate depths, even down to 300 metres, were enclosed by the isotherm in question. These differences demonstrate two kinds of variations; a different rate of heating from above, and different temperatures of the Atlantic water that enters the Norwegian Sea. In 1903 and 1904, the areas enclosed by the 8°-isotherm at the surface, were much narrower than in 1901, in spite of the later date of the observations. In 1903, however, great masses at intermediate depths had temperatures above 8° C., as in 1902; while in 1904 these masses were very small, almost as in 1901, but the section shows indications of the heating on the surface having commenced.

Figs. 53—56 show the conditions seawards from Lofoten, between the 15th and 18th of May, in 1901 and 1902, and between the 30th of May and 3rd of June, in 1903 and 1904. Conspicuous variations are found along this section too. The area enclosed by the isohaline of 35 ‰ is found to be:

in	1901	1902	1903	1904	
	251	230	229	203	square kilometres.

The greatest area of Atlantic water was thus found in May, 1901, and the smallest in May, 1904.

It is rather remarkable that the isotherm of 2° C. was found at the surface at nearly the very same distance from land during all the four years. But the course of this isotherm differs somewhat in the intermediate layers. Fig. 57 demonstrates the course of the isotherm of 4° C. in the years 1901—1904, in the latter half of May and the beginning of June. The area enclosed by the 4°-isotherm had the smallest extent in 1901, and the greatest in 1903 and 1904. Fig. 58 shows analogous variations of the isotherm of 6° C. The variations may however, to some extent, be due to the fact that the observations of 1903 and 1904 were taken about a fortnight later in the season.



Figs. 53—56. Sections seawards from Lofoten, May and June, 1901—1904.

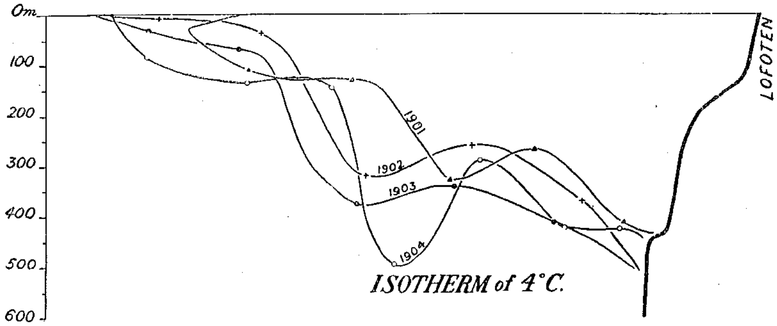


Fig. 57. Isotherm of 4 ° C., in Lofoten Section, May and June, 1901—1904.

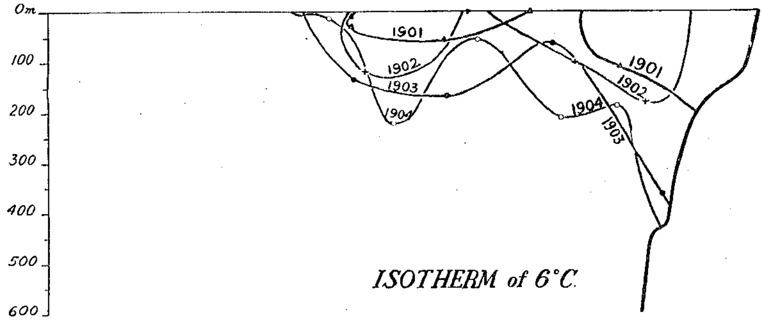


Fig. 58. Isotherm of 6 ° C., in Lofoten Section, May and June, 1901—1904.

We have made an attempt to find, approximately, the average temperature of the Atlantic water occurring in the sections seawards from the Sognefjord and seawards from Lofoten. The results will be found in the following four Tables (A—D). We have divided our material into surface-observations and observations made below the surface (1); and the mean temperature has been calculated for different salinities above 35·00 ‰. In the calculations of the mean temperature of the waters below the surface, the differences of depth have not been taken into account. We have included the observations taken in May, 1905, along the southern section (cf. Fig. 52); but no observations were made at that time off Lofoten.

(1) For our calculations of the mean temperatures below the sea-surface, in the southern section, only the observations from Stat. 3 and westwards have been taken into account.

A. *Mean Temperature at the Surface along the Sognefjord Section, for different Salinities above 35·0 ‰ (Middle of May).*

S ‰.	1901 V, 5—9.	1902 V, 7—11.	1903 V, 23—25.	1904 V, 22—25.	1905 V, 16—18.	Average 1901—1905.
35·00— ·09	7·02	3·59	6·02	5·40	5·67	5·54
·10— ·19	7·70	5·67	7·04	6·62	7·11	6·83
·20— ·29	7·94	7·08	7·52	7·55	7·98	7·61
Above 35·30	8·30	7·57	8·41	8·30	8·27	8·17
Above 35·00	7·85	6·99	7·41	7·37	7·81	7·49

B. *Mean Temperature at the Surface along the Lofoten Section (End of May).*

S ‰.	1901 V, 16—18.	1902 V, 16—17.	1903 V, 31—VI, 1.	1904 VI, 1—3.	Average 1901—1904.
35·00— ·09	3·80	4·73	6·95	6·08	5·39
·10— ·19	5·90	5·67	7·43	7·38	6·60
Above 35·20	6·11	6·75	—	(7·30)	(6·72)
Above 35·00	5·47	5·58	7·31	7·35	6·43

C. *Mean Temperature at Intermediate Depths. The Sognefjord Section (Middle of May).*

S ‰.	1901 V,5—8.	1902 V, 7—10.	1903 V, 23—25.	1904 V, 22—24.	1905 V, 16—18.	Average 1901—1905.
35·00— ·04	3·98	(4·34)	—	5·24	3·63	4·30
·05— ·09	4·85	(5·19)	4·85	5·25	5·10	5·05
·10— ·14	5·95	(5·12)	5·81	6·44	—	5·83
·15— ·19	6·36	6·49	6·53	6·72	6·29	6·48
·20— ·24	6·97	7·18	7·24	7·19	7·31	7·14
·25— ·29	7·50	7·84	7·74	7·57	7·19	7·57
Above 35·30	—	8·37	8·16	8·32	7·81	8·17
35·00— ·19	5·18	6·01	6·12	6·11	5·24	5·73
Above 35·20	7·16	7·71	7·63	7·38	7·32	7·44
Above 35·00	6·20	7·24	7·23	7·04	6·79	6·90

D. *Mean Temperature at Intermediate Depths. The Lofoten Section (End of May).*

S ‰.	1901 V, 16—18.	1902 V, 15—18.	1903 V, 31—VI, 1.	1904 VI, 1—3.	Average 1901—1904.
35·00— ·04	2·67	3·47	4·21	4·22	3·64
·05 — ·09	4·34	4·75	5·62	5·36	5·02
·10— ·14	5·31	5·85	6·10	5·94	5·80
Above 35·15	6·12	6·32	6·93	6·44	6·45
Above 35·00	4·56	4·96	6·23	5·94	5·42

The mean temperatures for intermediate depths (Tables C and D) are certainly too high, as most observations have been made in the upper, warmer strata. But the number of observations in the upper strata, as compared with the observations from greater depths, was less in May, 1901 and 1902, than in the other years. In May, 1901 and 1902, observations were taken af 0, 25, 50, 75, 100 metres etc., but in the other years generally at 0, 10, 20, 30, 50, 75, 100 metres etc. The mean temperatures of the two first years, 1901 and 1902, are therefore a little lower, comparatively, than the mean temperatures of 1903—1905. The fact that the observations in the two first years were taken at an earlier date than in the later years will have a similar effect. But as the observation-material is not complete enough for an exact calculation of the real mean temperature of the Atlantic Current, we have not considered it worth while to use more exact statistical methods.

We have also calculated the mean temperature of the Atlantic Water at 50 and 200 metres, along the southern and northern sections, in the same manner as for the surface (Tables A and B), and have obtained the following values:

E. *Mean Temperature of Water with Salinities above 35·00 ‰.*

Along the Sognefjord Section (Middle of May).					
	1901.	1902.	1903.	1904.	Average.
At the Surface	7·85	6·99	7·41	7·37	7·41
» 50 metres	6·44	7·37	7·48	7·16	7·11
» 200 »	5·71	6·83	6·69	6·95	6·55
Along the Lofoten Section (End of May).					
	1901.	1902.	1903.	1904.	Average.
At the Surface	5·47	5·58	7·31	7·35	6·43
» 50 metres	5·27	5·49	6·77	6·16	5·92
» 200 »	3·99	4·44	5·91	5·70	5·01

We shall here especially call attention to the following results demonstrated by the above tables:

The Tables A to D show clearly that the highest salinities in May are always associated with the highest temperatures, both at the surface and in the intermediate strata, in both sections. This is the case in all seasons, except in summer at the eastern boundary of the Atlantic Current, near the Norwegian Coast Water.

Table E shows that in May the highest temperatures will generally be found at the surface, an exception from this rule, however, being found in the southern section in 1902, and to a small degree in 1903. May is therefore the critical month as regards the heating of the surface; earlier in spring the maximum temperatures will in all probability be found at intermediate depths, and later in the season at the surface, owing to the cooling of the surface during winter and the heating from above during summer. The time at which a thermic equilibrium between atmosphere and hydrosphere is established has thus been subject to variations in the southern part of the Norwegian Sea: it occurred early in 1901, and late in 1902 and 1903. In this part of the sea (the Sognefjord Section) the thermic conditions at the surface do not present a parallel to the conditions at intermediate depths, *i. e.* in the main body of the current. Table E shows that while the surface-temperature was much lower in 1902 than in 1901, the relations were reversed at 50 or 200 metres, where it was much warmer in 1902 than in 1901. The surface-temperature gives therefore no reliable expression for the thermic conditions of the Atlantic Current in the Norwegian Sea.

Even if our statistical method is inaccurate, the differences in spring between the years 1901—1904, as revealed by Tables C and D, may probably give fairly trustworthy results. Basing our comparisons upon the average temperatures of the Atlantic water for May, as found in these tables, we obtain the following differences from the normal value (6·90° C. for 5 years) along the southern section (Table C):

In	1901	1902	1903	1904	1905
Difference	— 0·7	+ 0·3	+ 0·3	+ 0·1	— 0·1° C.

The Atlantic water was thus much colder in May, 1901, than usual, even if the surface-temperatures were considerably higher (+ 0·4° C.) than the average. In May, 1902, the Atlantic water in the southern part of the Norwegian Sea was considerably warmer than the normal, but with an abnormally low temperature at the surface. Along the northern section, off Lofoten, we find in the same way the following differences from the average (5·42° C. for 4 years):

In	1901	1902	1903	1904
Difference	— 0·9	— 0·5	+ 0·8	+ 0·5° C.

The differences found in the northern section are thus considerably greater than those found in the southern part of the sea, just north of the Færoe-Shetland Channel. 1901 shows abnormally low temperatures. It is especially noteworthy that the mean temperature in 1902 was also much lower than usual in this northern part of the sea, while it was much higher to the south. The comparatively cold waters found in the Lofoten section in May, 1902, will by and by be replaced by the unusually warm waters coming from the south; it seems as if a "heat-wave", so to speak, were proceeding northwards in 1902, where comparatively cold water was found before.

The thermal conditions vary in the Lofoten section in the same manner as in the Sognefjord section, but a year in the north corresponds nearly to the preceding year in the south. We had thus unusually high temperatures in the southern section in 1902 and 1903, and in the northern section in 1903 and 1904. The following figures represent the difference between the mean temperature of the Atlantic water at intermediate depths of the Sognefjord section in May of one year and the corresponding temperature of the Lofoten section in May of the next year:

1901—2	1902—3	1903—4
1·24° C.	1·01° C.	1·29° C.

The *variations in this difference are strikingly small, only amounting to* 0·2 or 0·3° C.(1) For the sake of comparison we may mention that the difference in the Sognefjord section between 1901 and 1902 was 1·04° C., and in the Lofoten section between 1902 and 1903, as much as 1·27° C. The variations within the same section may thus be much greater than the variations in the differences between the two sections calculated for two successive years.

We do not know at present, with sufficient certainty, how long time the whole volume of Atlantic water, occurring in the sections, requires, on the average, for travelling from the Sognefjord section to the Lofoten section. The agreement between the mean temperatures of the southern section a year afterwards might indicate that the water used about one year for the passage between the sections,

(1) The corresponding differences between the mean intermediate temperatures of the two sections in the same years are the following:

1901	1902	1903	1904
1·64° C.	2·28° C.	1·00° C.	1·10° C.

They are consequently much more variable.

which would correspond to an average velocity of 1 naut. mile in 24 hours. This agrees well with our calculations of the mean velocity of the whole volume of Atlantic water, (pp. 165—167), according to which it travels on the average between 1 and 2 naut. miles in 24 hours in a northward direction. It is extremely difficult to calculate the actual velocity, as long as we know no more about the movements in the different parts of the current.

Our calculations show that at least in some parts of it the velocities are considerably greater, while in other parts the movements are less or even minus, *i. e.* are directed southwards. Provided that the mean velocity of the whole volume of Atlantic water, or at least that part of it which has the greatest temperature-variations, be more than 1 mile in 24 hours, it is the water passing through the Sognefjord section in some month after May of the one year which is found in the Lofoten section of the following year. If, for instance, the mean velocity be 1·5 mile in 24 hours, the Atlantic water occurring in the Lofoten section in May would have passed through the Sognefjord section in September of the previous year. If, moreover, the anomaly of temperature of the Atlantic water passing through the Sognefjord section was greater in September,(1) 1901, (*i. e.* the relative temperature of the water, as compared with its normal for the month, was lower) than in May, 1901, it is obvious that the difference between the mean temperatures of the Sognefjord section of May, 1901, and of the Lofoten section of May, 1902, would be greater than usual, even if the cooling of the water-masses on the way was exactly the same as in other years. The observations indicate, however, that there has probably been a rise in the relative mean intermediate temperature (*i. e.* as compared with the normal of the month) of the Atlantic water in the Sognefjord section during 1901 and the first part of 1902. The unusually low mean temperature of the Lofoten section in May, 1901, indicates that in the previous year (1900) the mean temperature of the Sognefjord section has been comparatively still lower than it was in May, 1901.(2) We may thus assume that on the whole there has been a rise in the relative intermediate temperature of the Atlantic water of the Sognefjord section from some month in 1900, to some month in 1902.

But if on the other hand we assume that this rise of the relative water-temperature has not stopped until the autumn, and that a fall in the temperature has commenced after September 1902, so that the mean intermediate temperature of the Atlantic water of the Sognefjord section was comparatively higher in September, 1902, than in May, 1902, then there would naturally be less difference in temperature than usual between the Sognefjord section of May, 1902, and the Lofoten section of May, 1903. It is therefore possible, that if we could obtain a more complete

(1) Or in the month when the Atlantic water of the Lofoten section of May, 1902, passed through the Sognefjord section.

(2) Our observations during the cruise in July and August, 1900, seem to indicate comparatively low temperatures in the water of the Norwegian Atlantic Current [cf. NANSEN, 1901, pp. 142—146].

observation-material for the different months of the year, we should find a more perfect agreement between the variations of the temperatures in the two sections.

As it is, we may, however, assume that the thermal conditions of the Atlantic water in the Lofoten section depend upon two factors; namely, the original temperature of the Atlantic water before it passes through the Sognefjord section, and the rate at which this water is cooled on its way northwards.(1) The first factor is pobably the more important one.(2)

We have thus found certain annual variations in the volume (or rather in the sectional area) of the Atlantic water, and in the mean temperature of this water. By multiplying the sectional area (A in square kilometres) and the mean temperature (t) we may obtain some values corresponding to *the quantity of heat stored in the Atlantic water* in the spring of the different years. The following tables contain some results of such calculations.

Southern Section.

Year.	t° C.	W. of Stat. 3.		The Whole Section.	
		A km.^{2}	$A \times t$	A km.^{2}	$A \times t$
1901	6·20	84	521	148	918
1902	7·24	112	811	155	1122
1903	7·23	107	774	149	1077
1904	7·04	87	612	135	950
1905	6·79	138	937	184	1249
Average	6·90	106	731	154	1063

(1) This rate may depend upon the meteorological conditions, especially the *differences in temperature* between the Atlantic water and the atmosphere, and the *quantity of sun heat* reaching the sea-surface through the atmosphere, as well as the *radiation of heat* from the water-surface. But to some extent it will also depend upon the conditions in the sea, especially the vertical distribution of salinity. If the sea be covered by a surface layer of coast water with low salinity, this will reduce the vertical circulation created by the cooling during the winter and will reduce the cooling of the Atlantic water.

(2) As will be mentioned later, this factor (*i. e.* the temperature of the water, having a salinity above 35·0 ‰, in the Sognefjord section) may depend partly upon the temperature which this water had when coming across the Wyville Thomson Ridge (and the Færoe-Iceland Ridge) from the Atlantic. But it will also depend upon the salinity of this water, and upon the temperature, salinity, and quantity of the water with which it is intermixed in the Færoe-Shetland Channel, and on its way north-eastwards.

Northern Section.

Year.	t° C.	A km.^{2}	$A \times t$
1901	4·56	251	1145
1902	4·96	230	1141
1903	6·23	229	1427
1904	5·94	203	1206
Average	5·42	228	1230

The product, $A \times t$ (of area, A, and mean temperature, t), varies rather much; it shows small quantities of heat in the southern section in 1901 and 1904, and large quantities in 1902 and especially in 1905. The variation from 1904 to 1905 is not parallel to the variation in the mean temperature, on account of the great difference in the sectional areas of the two years. In the northern section there was a small amount of heat in 1901 and 1902, and a large amount in 1903. We have the same coincidence in this respect between the southern section in one year and the northern section in the following year, as was demonstrated by the mean temperatures. It will be seen that in spite of the low mean temperature in the northern section of 1901 the amount of heat was a little greater that year than in 1902, because the sectional area of the Atlantic water was considerably greater in 1901 than in 1902. It agrees with the observations from the southern Norwegian Sea in the summer of 1900, when it was found that the temperature of the Atlantic water was unusually low, but the volume unusually great [cf. NANSEN, 1901].

Variations in the Temperature of the Atlantic Water in the English Channel and in the Færoe-Shetland Channel. It would be of much interest if we could come to some conclusion whether the variations found in the mean temperature of the Atlantic water of the Sognefjord section are chiefly due to variations in the temperature of the water masses carried by the Atlantic Current into the Norwegian Sea, or whether they have other causes. From three observation stations [*Bulletin,* E 4, 5, & 6] along a section near the edge of the continental shelf at the entrance to the *English Channel* there are *English observations* from the spring of 1903, 1904, and 1905.(1) As the Atlantic water at these stations has at least to some extent been carried by the North Atlantic Current (Gulf Stream) it may give some information about the variations in the temperature of this current. We find the following means of all temperature observations at these stations:

(1) Cf. *Bulletin des résultats*, etc. Copenhagen.

1903, May 15—16,	mean temperature	=	11·12° C.
1904, April 28—29,	» »	=	9·64 »
1905, May 14—15,	» »	=	10·58 »

As the observations in 1904 were taken more than two weeks earlier in the season than the year before and after, it is evident that their mean temperature is comparatively too low. It is therefore probable that the mean temperature has been lower in May, 1904, than in May, 1903, but possibly higher than in May, 1905. We may consequently assume that the mean temperature of the Atlantic Current represented by these waters has been decreasing in the three years 1903, 1904, and 1905. It is probable that the water occuring at the English stations at the entrance to the English Channel, corresponds to water carried by the Atlantic Current which reaches our Sognefjord section considerably later, and it is even possible that the water occurring at the English stations in May, 1903, corresponds more to the Atlantic water occurring in the Sognefjord section in May, 1904, than to that of the same year. But in both cases the variations in the mean temperature of the English sections in 1903—1905 have a certain resemblance to the variations in the mean temperature of the Sognefjord section; or, at any rate, the observations do not disprove the possibility of an agreement, although nothing certain can be concluded from observations of two or three years only.

The *Scottish observations in the Færoe-Shetland Channel* of May, 1903, 1904, and 1905, might be expected to give more trustworthy information about the temperatures of the Atlantic water entering the Norwegian Sea. The difficulty is, however, that there are evidently great, and apparently irregular and sudden, local variations in the water-strata in this narrow channel, where the waters run with great velocities, and where vortices and other complicated movements continually arise. We have, nevertheless, made an attempt to calculate the mean temperature of the Atlantic water running through the Færoe-Shetland Channel into the Norwegian Sea. We have only made use of the observations taken at the stations on the Shetland side of the channel, as the Atlantic water at the stations on the Færoe side may have come north of the Færoes. We have found the following mean temperatures for the Atlantic water below the surface(1) in the two Scottish sections across the Færoe-Shetland Channel:

May,	1903	1904	1905
Southern Section (Stats. 19 A, 19 B, 20 B). . . .	7·20° C.	7·38° C.	8·28° C
Northern Section (Stats. 12—15 A)	7·60° C.	7·23° C.	7·67° C.

It seems difficult to discover any parallelism between the annual variations in these two sections and in our Sognefjord section. In the southern section the mean temperature appears to have been rising from May, 1903, to May, 1905, while in the Sognefjord section it was falling during those years. In the northern section it is a little better. The mean temperature is lower in May, 1904, than in May, 1903, but also lower than in May, 1905, which does not agree with the variations in the Sognefjord section.

(1) The mean temperature has been calculated only by means of observations made at the same depths in those three years.

If anything the mean temperatures of these sections across the Færoe-Shetland Channel, seem to prove that the annual variations in the mean temperature of the Atlantic water in the Sognefjord section are not chiefly regulated by the variations in the temperature of the Atlantic water entering the Norwegian Sea, but may have some other cause. It might then seem natural to think of possible variations in the *East Iceland Arctic Current.* It is, for instance, possible that a comparatively great quantity of Arctic water (cf. Chap. IX) carried, along the northern slope of the Færoe Platform into the mouth of the Færoe-Shetland Channel might, to some extent, check the Atlantic Current, and by partial intermixture (*e. g.* by the vortex-movements in the Channel) it may cool the Atlantic water more than usually before it reaches the region of the Sognefjord section, while a comparatively small quantity of Arctic water carried into the Channel will have less effect.

We have not sufficient observation-material to trace the annual variations in the quantity of Arctic water carried by the East Iceland Arctic Current along the slope of the Færoe-Iceland Ridge. According to the Danish observations it seems as if there was less Arctic water, with salinity below 34·90 ‰, carried by this current eastwards north of the Færoes in May, 1903 (see the tongue in Pl. XXI B, Figs. 3 & 4) than in May, 1904 (see Pl. XXIV B, Figs. 3 & 4). But in May, 1905, the Danish observations at the stations (Da 2—Da 4) north of the Færoes indicate hardly any water of this kind.

In our Sognefjord sections we find that the Arctic Water forming the "tongue" (with salinity below 34·90 ‰) was well developed in May, 1904, and even still more in May, 1901, and with lower temperatures, the isotherm of 2° C. being almost entirely above the tongue. In May, 1902, there was hardly any indication of it (see Pl. XVII, Fig. 1). only a salinity of 34·90 ‰ at Stat. 6, 400 metres. In May, 1903, the "tongue" seems to have been divided into two parts in the Sognefjord section (Pl. XXI A, Fig. 1) and was evidently not so well developed as in May, 1904 (Pl. XXIV A, Fig. 1). In that season there was even a great volume of this water in the Stad section. But in May, 1905, the „tongue" does not seem to have been much developed in the Sognefjord section which agrees with the observations at the Danish stations north of the Færoes of the same month.

As far as these observations go, they agree fairly well (with the exception of May, 1905) with the assumption that the variations in the mean temperature of the Atlantic water of the Sognefjord section may be more or less caused by variations in the East Iceland Arctic Current, or at least, they do not disprove it. But the observation-material is so small that we can base no conclusions on it.

We have pointed out before that *the Atlantic water in the western North Sea* runs chiefly north of the Shetlands and southwards east of these islands. It might therefore be expected that the annual variations in the May temperature of this water show better agreement with the variations in our Sognefjord section. It has, however, to be considered that the North Sea, even in its north-western part is very shallow, and the temperature of its Atlantic water is probably much influenced by local conditions. We find the following mean temperatures in May of the Atlantic water in the two Scottish sections across the northern part of the North Sea, from the Shetlands to the Norwegian Channel.

	May,	1903	1904	1905
Scottish Stats.	5—7	7·91 ° C.	7·87 ° C.	7·39 ° C.
» »	10—12	8·09 ° C.	8·30 ° C.	8·12 ° C.

The annual variations in the first section agree well with those in the Sognefjord section, but the variations in the last section, which is farther north than the other, do not agree as well, the temperature in May, 1903, being lower than in May, 1904.

Variations in the Temperature of the Water and in the Distribution of the Ice in the Barents Sea. By means of the observations, chiefly by Norwegian sealers, of the distribution of ice, and the Russian observations of the water-temperature in the Barents Sea, during recent years, we can obtain some information about the variations in this region, which are of much interest in connection with our observations farther south.

Along a section northwards from Kola, in about 33 ° 30 ′ E. Long., the Russians (Dr. KNIPOWITSCH and Dr. BREITFUSS) have taken observations in May 1900, 1901, 1903, 1904, and in June 1902. There are three stations, (we will call them A, B, and C) between 71 ° and 72 ° N. Lat., in this section, from which there are observations in each of these years. (1) By taking only the temperature-observations at the same depths at each of the stations into account, we find the following mean temperatures for each year:

	A 71 ° 00 ′ N. 33 ° 30 ′ E.	*B* 71 ° 30 ′ N. 33 ° 30 ′ E.	*C* 72 ° 00 ′ N. 33 ° 30 ′ E.	Mean for all three Stats.
1900, May 28—30	2·51 ° C.	2·86 ° C.	2·40 ° C.	2·59 ° C.
1901, May 27—31	2·09 »	2·64 »	2·37 »	2·37 »
1902, June 11—16	2·24 »	2·67 »	2·10 »	2·34 »
1903, May 3—4	2·27 »	2·55 »	1·84 »	2·22 »
1904, May 9—10	2·79 »	3.02 »	2·39 »	2·73 »

(1) The observations are given in the sections, of Dr. KNIPOWITSCH for 1900 and 1901 [1906, Pls. III & II], and of Dr. BREITFUSS for 1902 [1903, Pl. II, 1904, Pl. 4,

It has to be considered that in 1900 and 1901 the observations were taken 24 days later in the season than in 1903, and 17 days later than in 1904. while in 1902 they were taken two weeks later than in 1900 and 1901. We must consequently expect that the heating of the sea-surface in the spring has raised the mean temperature of some of the sections as compared with the others. By comparing the temperatures vertically at each station, we find that in 1903, 1904, and also in 1901, there cannot have been any appreciable heating of the surface-layers, for there are nearly uniform temperatures at all depths from the surface and down to 50 or 100 metres, and at some stations even deeper. In 1900, there has evidently been a heating of the upper water-strata of about 0·8 °C., because the surface-temperature is about so much higher than the temperature at 100 metres, at all three station. In June, 1902, there has been a considerable heating of the surface-strata, because the temperatures rise upwards, at all depths, from the bottom-strata to the surface. In order to eliminate, at least to some extent, the effect of the heating of the surface-layers we have taken the means of the temperatures at 100, 150, and 200 metres, and find the following values:

Mean t° C. at 100, 150, & 200 Metres.

	A	*B*	*C*	Mean.
1900 May	2·03 ° C.	2·53 ° C.	2·03 ° C.	2·20 ° C.
1901 May	1·93 »	2·60 »	2·17 »	2·23 »
1902 June	1·64 »	2·31 »	1·77 »	1·91 »
1903 May	1·97 »	2·55 »	1·63 »	2·08 »
1904 May	2·86 »	3·35 »	2·14 »	2·78 »

But even these mean values of temperature are naturally somewhat influenced by the difference in seasonal time. The water which was observed between 100 and 200 metres at the three stations in June, 1902, for instance, may perhaps not have been essentially

VIII]. The observations of May, 1903 and 1904, are published in the *Bulletin d. rés.* etc. for these months. There are slight differences in the locality of the stations. Stat. *A* was in May, 1900, in 70 ° 55 ′ N. Lat., Stat. *B* was in May, 1900, in 71 ° 26 ′ N. Lat., 33 ° 45 ′ E. Long., in May, 1903, in 71 ° 25 ′ N. Lat. Otherwise the stations were situated, as given in the Table.

heated from above, but it is obviously probable that the water at these depths was warmer in June than it would have been in May of the same year, because the water met with in June had during the preceding month travelled from a region to the west where in May the waters, between the surface and the bottom, had been less cooled by the vertical circulation during the winter than in the region of the section (along 33 ° 30 ′ E. Long.). We may consequently assume that the mean temperature (1·91 ° C.) of June, 1902, is too high as compared with the mean temperatures of the other years. This assumption is confirmed by other facts. Observations taken in August, 1902, prove that the waters of the Barents Sea was much colder at that time than in August of the following year, 1903, when, however, it was also comparatively cold. The following mean temperatures may be of interest to show the difference between August, 1902 and 1903.

Station.	N. Lat.	E. Long.	Date.	Mean t ° C. for all Depths(1).
R 78	74 ° 00′	33 ° 30′	Aug. 16, 1902	0·65 ° C.
R 79	73 ° 48′	33 ° 30′	Aug. 16, 1902	2·33 »
R 15	74 ° 00′	33 ° 25′	Aug. 9, 1903	3·79 »
R 16	73 ° 30′	33 ° 20′	Aug. 9, 1903	4·07 »

These values show a striking difference between the two years, the mean temperature at Stat. R 78 in Aug., 1902, was more than 3 ° C, lower than at Stat. R 15 (very nearly in the same locality) in Aug. 1903, and even at Stat. R 79 it was 1·46 ° C. colder in Aug., 1902, than at Stat. R 15 in Aug., 1903, althought it was 12 miles farther south, and althoug the observations in 1902 were taken a week later in the season than in 1903. It proves that the sea has been much colder in the summer of 1902 than in 1903. There are no observation-stations, farther south, from the two years, which can be used for comparison. But as will be mentioned presently the distribution of the ice in May of the two years, also prove clearly that the sea has been much colder in the spring and summer of 1902 than in the following year. We consider it probable that the mean

(1) The means are taken of the observations at 0, 10, 25, 50, 100, 150, 200, and about 270 (or 300) metres.

temperature of the water at the three Stations (*A*, *B*, and *C*) was at least 0·5 ° C. lower in May, 1902, than in May, 1901 and 1903, and probably still lower. We assume accordingly that the mean temperature of the strata between 100 and 200 metres was 1·70 ° C. in stead of 1·91 ° C.

The main body of the *ice* of the Barents Sea is not Polar ice, but is formed during the winter and spring in this sea, where it also melts, to the greater extent, during the summer. It is therefore to be expected that the distribution of the ice, or rather the quantity of ice, in the sea in the spring, is to a very great extent dependent on the quantity of heat contained in the water-masses of the Barents Sea during the winter, and it is probably to a less extent dependent on the annual variations in the temperature of the atmosphere. It is therefore also probable that the distribution of ice in the Barents Sea in the spring is less dependent on other meteorological conditions (the distribution of atmospheric pressure and the winds) than it is in other parts in the Arctic regions, *e. g.* north of Iceland and Jan Mayen, although the wind has naturally everywhere influence upon the ice.

By means of the charts of the distribution of the ice, published, by Intenational agreement, by the *Danish Meteorological Institute* (editor V. GARDE), it is possible to get some idea of the annual variations in this distribution in the Barents Sea. The charts for May in the years from 1900 to 1908, seem to be based on a sufficiently great number of observations for giving fairly trustworthy representations of the distribution of the ice, although the lack of observations in some parts of the sea has made the ice-limit somewhat doubtful in some years.

By measuring with the planimeter the areas of open water in the Barents Sea east of 20 ° E. Long.(1) we have found the following values for May:

May	1900	1901	1902	1903	1904	1905	1906	1907	1908
Thousands of Square Kilometres	440	398	249	469	696	639	576	645	568

We have mentioned above that the water-masses of the Atlantic Current need a long time to flow from our Sognefjord section to our Lofoten section, and we have supposed that nearly a year may be

(1) The inner basin of the White Sea has not been considered.

required. The distance between the Lofoten section and the Russian section, along the meridian of 33° 30′ E. Long., northwards from Kola, is even considerably greater, and we may consequently assume that the water-masses will require another year to reach the Barents Sea. If this assumption be correct, it is probable that the variations in the Atlantic water of the Sognefjord section may be more or less traceable in the variations, both in the temperature of the water and in the distribution of ice, in the Barents Sea two years later It has, however, to be considered that the water running into the Barents Sea is a mixture of the Norwegian coast-water and Atlantic water. It cannot therefore be expected that the variations in the temperature of the Barents Sea shall follow exactly the variations in the Atlantic water of the Sognefjord section two years earlier, and of the Lofoten section one year earlier. But some indications of similar periods may, nevertheless, be traceable, provided that the variations in the Norwegian coast-water have not been so great that they entirely overshadow the effect of the variations in the Atlantic water.

The observations of salinity at the three Russian stations mentioned above, indicate great annual variations in salinity. The Russian observations give the following probable mean values for all three stations (*A*, *B* and *C*) in May, 1901, June, 1902, May, 1903 and 1904.

	1901	1902	1903	1904
Mean S ‰	34·75?	34·70	34·91	34·66

The value for May, 1901 is very doubtful, as there were determinations of the salinity only at the southern station, *A* [cf. KNIPOWITSCH 1906, Pl. II], and these determinations have hardly been very accurate. We have found our mean value, 34·75 ‰, by comparing the observations at this and another station in 72° 30′ N. Lat., 33° 30′ E. Long. with those at the same stations in 1903 and 1904. The mean value for June 1902 is also somewhat doubtful, as we had to take it from Dr. BREITFUSS's section [1903, Pl. II], where only the first decimal place of S ‰ is given. The mean values for May, 1903 and 1904, are probably more trustworthy. For May, 1901 and 1902, we have observations by which we can compute the volume and the mean salinity of the coast-water in the Sognefjord section, and we find that it had a comparatively small volume (cf. Fig. 88) and high salinity in May, 1901 (cf. Fig. 87), while its volume was great in May, 1902, and its salinity comparatively low. This corresponds to the variations in the Barents Sea two years later, with a high mean salinity in May, 1903, and a much lower mean salinity in 1904. Unfortunately we have no observations for earlier years that are comparable. But as will be mentioned in the following chapter, there is a relation between the precipitation *e. g.* in southern Norway, and the quantity of the coast water in the following spring. The precipitation for the whole year (expressed in percentage of the normal value) in Christiania and Bergen and for October to December at 25 stations in southern Norway was:

	1898	1899	1900	1901
Christiania	114	80	95	101
Bergen	136	131	111	105
25 Stats. in Southern Norway	92	101	106	120

These values do not, however, indicate less coast-water in May, 1901, than in May, 1899 and 1900.

A great volume of the coast-water in the Sognefjord section in May is accompanied by a comparatively low temperature of this water, and *vice versa.* We thus see, that these variations are not followed by the variations in the mean-temperature, of the section from the Barents Sea, and it therefore seems as if the latter variations chiefly depend upon the variations in the temperature of the Atlantic water, at least in those years from which we have observations. But, as the water flowing with the North Cape Current into the Barents Sea, is a mixture of Atlantic water and Norwegian coast water we may expect that the magnitude of the variations in the temperature of the Atlantic water, as seen in the Sognefjord section, are much reduced in the water entering the Barents Sea.

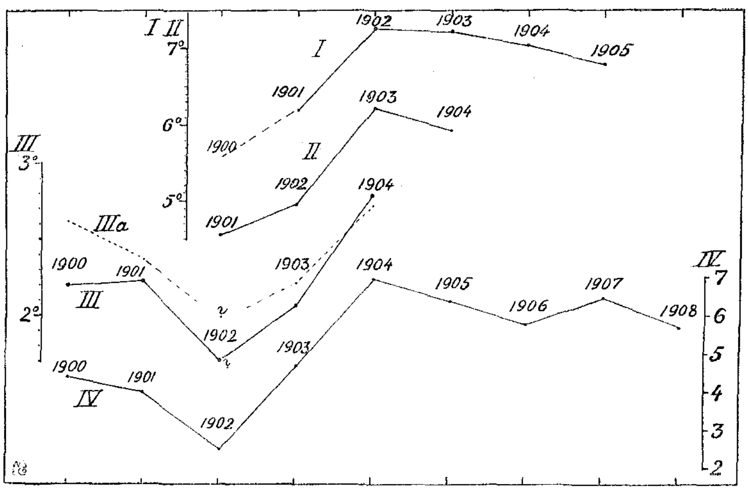


Fig. 59.

Fig. 59 gives a summary of our above discussion. The curves represent:

I the mean temperature of the Atlantic Water in the Sognefjord Section of May, 1901—1905 (scale to the left),

II the mean temperature of the Atlantic Water in the Lofoten Section of May, 1901—1904 (scale to the left), III the mean temperature of the water stratum between 100 and 200 metres at the three Russian Stations A, B, and C (see above p. 187) of May, 1900—1904(1) (scale to the left),

IIIa the mean temperature of the water, between surface and bottom, at the same stations,

IV the area (in hundred-thousands of square kilometres) of open water in the Barents Sea in May, 1900—1908 (scale to the right).

Upon the whole there is a better agreement between the Curves I, II, III, and IV, than we might have expected, considering the inaccurate methods, and it seems as if the variations occur one year later in the Lofoten section than in the Sognefjord section (see above p. 180) and two years later in the Barents Sea. There seems to be an exception in the distribution of the ice in May, 1907, as that was less than in 1906, although the mean temperature of the whole volume of Atlantic water in the Sognefjord section was lower in May, 1905, than in May, 1904. But there was a greater volume of Atlantic water with temperature above 8° C. in May, 1905, than in May, 1904, as is proved by Figs. 52 & 51. At the same time the entire volume of Atlantic water, and consequently also the quantity of heat, was unusually great in the Sognefjord section in May, 1905. The latter circumstance made the air-temperature of Norway comparatively high in the winter 1905—06 (cf. Fig. 60, and the water has consequently been less cooled during that year. The volume of coast water was also comparatively small in May, 1905, and the precipitation was unusually small in southern Norway in 1904 and in the winter 1904—05 (cf. Fig. 88, Curves II & V). It is therefore probable that the water carried into the Barents Sea in the winter and spring of 1907 has been comparatively warm, and this may explain the decrease in the distribution of the ice in May, 1907, as compared with May, 1906.

The above calculations do not claim to be exact, but it is, nevertheless, remarkable how well they agree with a number of meteorogical and biological facts. Some agreements of this kind will be discussed

(1) We have reduced the mean temperature (1·91° C.) found in June 1902, to 1·7° C. as being nearer the probable value for May 1902 (cf. above p. 189).

in the following pages, where the values tabulated above will be represented as curves in the figures.

2. The Relation between the Annual Variations in the Temperature of the Atlantic Current and the Variations in the Temperature of the Atmosphere.

As the Atlantic Current has a very great general influence upon the climate of Europe it seems *a priori* natural that variations in the thermal conditions of the current is followed by analogous variations in the temperature of the air. Professor PETTERSSON has in a number of papers tried to prove the relation between the Atlantic Current and the climate in this respect. He has thus explained the unusually high winter-temperature in 1897—98 as being caused by an unusually great development of the current in the latter half of 1897. But the observation-material at his disposal was very defective, and could not give fairly exact data as regards the variations in the quantity of heat stored in the Atlantic water. An observation-material sufficiently complete for this purpose, has in reality not existed before the investigations in the Norwegian Sea commenced in 1900. The observations collected since 1900 form therefore the only material from which numerical values of the variations in the Atlantic current can be calculated. For lack of observations from the ocean PETTERSSON made use of a long series of observations of the surface-temperature, collected at Ona Lighthouse. But the surface-temperature close to the coast has very little to do with the temperature of the Atlantic water; it shows merely the *effect* of the meteorological conditions, and not the *causes* of them, almost in the same manner as the temperature at the surface of a lake would do. PETTERSSON has so far made a mistake when he assumes that the observations at Ona Lighthouse may prove anything about the effect of the ocean upon the atmosphere. (1)

We have in the tables above, p. 182, given some values of the quantity of heat in the Atlantic water, calculated as a product of the

(1) MEINARDUS [1904] has made a similar mistake when he assumes that the variations in the temperature of the sea near the coasts — even in the shallow eastern part of the North Sea, at Horns Riff on the west coast of Jutland — indicate directly the variations in the temperature of the water carried by the Atlantic Current.

sectional area and the mean temperature *(A × t)*. The following table shows these values for the Sognefjord section and the mean anomaly of the air-temperature in Norway (average for 22 meteorological stations distributed all over the country) during the following winter from November 1st to April 30th (1):

	1901	1902	1903	1904	1905
Quantity of Heat in the Atlantic Water W. of Stat. 3	521	811	774	612	937
Dito. for the Whole of the Sognefjord Section	918	1122	1077	950	1249
Mean Anomaly of Air-Temperature from November to April (following winter)	— 0·4	+ 1·2	+ 0·6	+ 0·3	+ 1·0

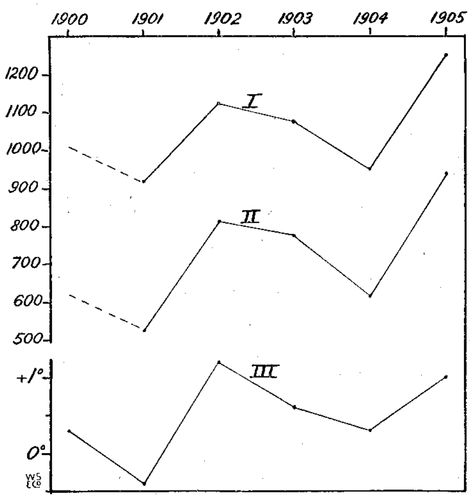


Fig. 60. I Quantity of Heat in Atlantic Water, in the Whole of the Sognefjord Section.
II Ditto, W. of Stat. 3.
III Mean Anomaly of Air-Temperature, following Winter, Nov.—April (for 22 Stations in Norway).

These values have been used for Fig. 60, where Curve I represents the values of the quantity of heat in the whole of the Sognefjord section, and Curve II the same for the part of the section west of Stat. 3; the curves are quite parallel to each other. The broken-lined part of the curve, between 1900 and 1901, is not based upon direct observations; but this course of the curve is probable, because the volume of the Atlantic water in 1900 was very great (cf. above p. 183). Curve III represents the mean anomaly of the winter temperature in Norway.

These three curves coincide almost perfectly.(2) It is evident

(1) The meteorological data here given have been taken from *Jahrbuch des norwegischen meteorologischen Instituts.* The 22 stations mentioned above are those from which sufficient observations exist for a long period.

(2) As regards the accuracy of the data upon which the Curves I and II are based, especially the relation between the observations of 1902 and 1903, see above p. 178.

that the air-temperature of the winter, from November to April, does not agree with the quantity of heat in the Atlantic water in the following May. *The winter-temperature is not the cause, but the effect of the thermal conditions of the Atlantic water, whose variations are followed by quite analogous variations in the temperature in Norway during the next winter.* It ought to be kept in view that this result as well as those set forth later, are based upon observations only from a small number of years, in this case 5 or 6 years. But the coincidence is so complete, that it seems hardly possible that it should be merely accidental. It seems more likely that we will be able to predict the mean temperature of the following winter from observations in the Norwegian Sea in May.

As the quantity of heat contained in the Atlantic water is a product of its mean temperature and its volume (sectional area) we cannot expect that there is a close parallelism between the annual variations in its mean temperature in the Sognefjord section and the annual variations in the winter temperature in the following winter, except in years when there has been no great variations in the volume of the Atlantic water. There is nevertheless a certain resemblance in the five years from which we have observations, and this resemblance is still greater if we take the mean air-temperature (for December 1st to May 31st) at a station in or near the sea, *e. g.* Ona Lighthouse (cf. Fig. 61), in stead of that of the whole of Norway. If we assume that some kind of resemblance occurs in most years, we may use the mean winter temperature at Ona as an indicator of what the variations in the temperature of the Atlantic water might possibly have been in earlier years, from which we have no observations. If, moreover, the annual variations in the mean temperature (below the surface) of the Atlantic water in the Sognefjord section in May, are followed by annual variations in the distribution of the ice in the Barents Sea, in May two years later, there ought to be some resemblance between the last mentioned variations and the variations in the winter-temperature at Ona Lighthouse, because they have probably to some extent the same cause, *i. e.* variations in the temperature of the Atlantic water of the southern Norwegian Sea.

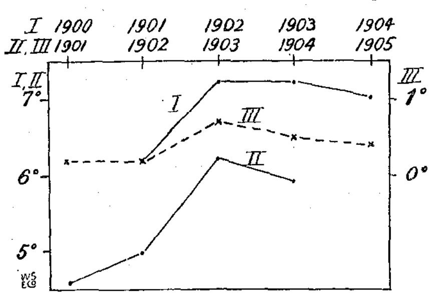


Fig. 61. I Mean Temperature of Atlantic Water, Sognefjord Section.
II Ditto, Lofoten Section.
III Mean anomaly of Air-Temperature at Ona Lighthouse Dec.—May.

Fig. 62 proves that this is, to some extent, the case. Curve I represents the area of open water in the *Barents Sea* in May, in the years 1900—1908 (cf. Fig. 59) Curve II represents the mean anomaly of the air-temperature in *Norway* (at 22

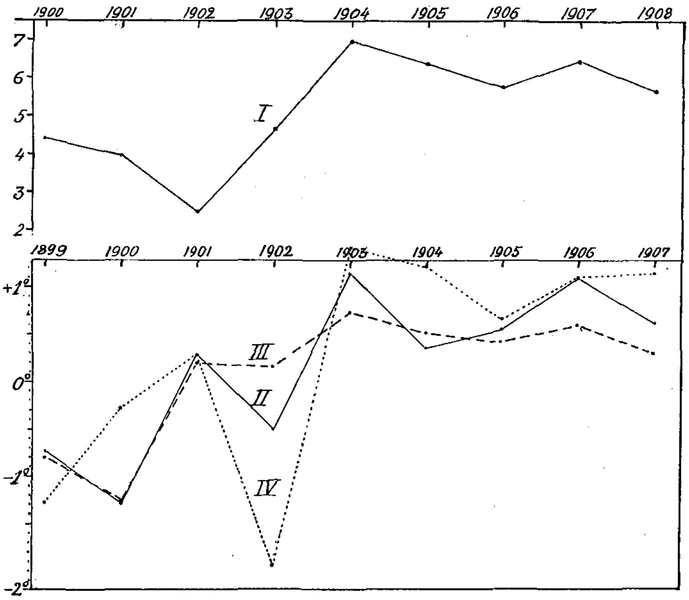


Fig. 62. I Area of Open Water in Barents Sea in May (in hundred-thousands of square kilometres).
II Mean anomaly of Air-Temperature of Norway Dec. 1—May 3.
III Ditto at Ona Lighthouse.
IV Ditto in Vardö.

stations) from December 1st to May 31st, in 1899—1907. (December is reckoned to the following year, so that *e. g.* 1899 means Dec. 1st, 1898, to May 31st, 1899).

Curve III represents the corresponding mean anomaly of the air-temperature at *Ona Lighthouse* (62° 52′ N., 6° 33′ E.)

The agreement between the three curves, especially between I and III, is fairly good in nine of these ten years. The mean air-temperature for Dec. 1st 1900 to May 1901 forms, however, an exception as it was fairly high, both in the whole of Norway and at Ona Lighthouse, while there was ecxeptionally much ice (or little open water) in the Barents Sea in May in the following year (May 1902). But we must expect to find such exceptions, because, as was pointed out above, the winter-temperature of the air seems to depend chiefly upon the *quantity* of heat stored in the Atlantic water (*i. e.* both its mean temperature and its volume) while the quantity of ice in the Barents Sea seems to depend more upon its *mean temperature.* In the summer of 1900 the Atlantic water seems to have been comparatively very cold in the southern Norwegian Sea (which is also proved by the low temperature of the Atlantic water in the Lofoten section of May, 1901), but it had a wide distribution and its volume was probably great (cf. p. 183). Its quantity of heat may consequently have been comparatively great, which explains the fairly high air-temperature in the following winter, while its low mean-temperature explains the exceptionally great distribution of ice in the Barents Sea two years later.

It might seem probable that there should be a close relation between the distribution of the ice in the Barents Sea and the winter temperature at Vardö in the same year. This is, however, not the case to any great extent; the winter-temperature at Vardö seems to a greater extent to follow that of the other parts of Norway, as is proved by Curve IV in Fig. 62. It is only in the exceptional year of 1902, that the exceptionally low winter-temperature in Vardö coincides with the exceptionally great quantity of ice in the following May. But in other years there is, if anything, a better agreement with the simultaneous mean air-temperatures of Norway and consequently with the distribution of ice in the Barents Sea one year later. This proves that it cannot be the variations in the temperature of the atmosphere which regulate the variations in the quantity of ice in the Barents Sea, but it is much more the variations in the temperature of the water-masses.

The northward movement of the Atlantic water passing through the Norwegian Sea is on the whole very slow, as was pointed out above (pp. 166, 181); because it is only a small part of it, close to the continental slope, that runs northwards with a considerable velocity, while the greater part moves, sometimes southwards, sometimes northwards, or in other directions. The result is that the great mass of Atlantic water, observed in the Sognefjord section in May, takes a long time, a year at least, to pass through the southern Norwegian Sea; it is still there during the following winter, and will then give off heat to the atmosphere.

We have mentioned above (p. 180) that the variations in the mean temperature of the Sognefjord section in May correspond nearly to the variations in the Lofoten section in the following May. The differences between the simultaneous (*i. e.* in the same year and month) mean temperatures, below the sea-surface, of both sections vary much from one year to another. These differences, from May, have been introduced in Fig. 63, Curve I. The broken-lined Curve II, in this figure, represents the mean anomaly of air- temperature at Skomvær (Lofoten), from January 1st to March 31st of the same year, *i. e.* some months before the observations in the sea. The coinsidence between these curves is very good. It shows that a great difference corresponds to a low winter-temperature, and *vice versa*. This agrees well with what has been said above; a great difference of temperature between the sections in the same year indicates that the Atlantic water of the Lofoten section which has entered the Norwegian Sea at some earlier period, has been much colder than the water which entered the sea recently, and is found in the Sognefjord section. It is this "older" water that, during its passage through the Norwegian Sea, has determined the character of the winter-temperature of the air.

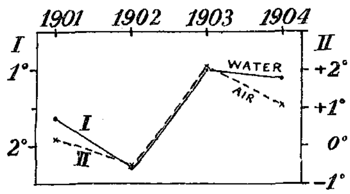


Fig. 63.

The following simple calculations may serve to show that the thermic conditions of the sea can have a very great effect upon those of the atmosphere. We have previously found that more than 100 000 cubic kilometres of Atlantic water flow into the Norwegian Sea every year. If in a certain year, this quantity be cooled 0·1 °C, more than usual, and the whole quantity of heat corresponding to this cooling be given off to the amosphere, 33 million cubic kilometres of air would be heated on an average 1 ° C.(1) This quantity corresponds to a layer of air with a height of 1000 metres and an area three times as great as that of Europe. It is therefore evident that those fluctuations in the mean temperature of the Atlantic water which are due to exchange with the atmosphere, will correspond to thermic fluctuations in enormous quantities of air.

The above discussion has been based upon the conditions of the water of the Atlantic current without taking the surface-temperature into account. The Atlantic water at intermediate depths seems to have a conclusive influence upon the temperature-conditions of Norway. It is much to be regretted, however, that no sufficient number of observations exists from other seasons, during a series of years, so as to show with certainty the development and changes of the mean temperature of the Atlantic water.

It was pointed out above (p. 179) that the variations in the mean temperature at the surface differ much from the variations at intermediate depths. The mean surface-temperature of the Atlantic water along the Sognefjord section in May of different years has been introduced in Fig. 64, the unbroken line *A*. The entire line *B* represents the mean anomaly of the air-temperature at *Ona Lighthouse* (62 ° 52 ′ N., 6 ° 33 ′ E.) in the following July; and the broken-lined curves (*C*) represent the mean anomaly for the above-mentioned 22 stations in Norway, IV for April, V for May, and VI for June. On comparing *A* with the other curves, we find that there is no marked agreement with the curve for April, but a very distinct one with those for the following months, even for July (*B*). The curve for May (*V*) shows especially a close agreement with the temperature-curve for the sea-surface of the same month, as was to be expected. It is a general feature that a high

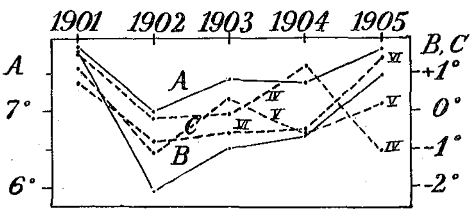


Fig. 64.

(1) The specific heat of atmospheric air is about 0·238, and the absolute specific gravity 0·0013. As the specific gravity of seawater is about 1·0275, we find that the heat required for heating 1 cubic metre of water 1 ° C. will be able to heat $\frac{1{\cdot}0275}{0{\cdot}0013 \times 0{\cdot}238}$, or more than 3300 cubic metres of air 1 ° C.

temperature of the Atlantic surface-water in May corresponds to high air-temperatures in the following months.

We have mentioned above (pp. 174, 179) that the Sognefjord sections of different years show differences in the heating of the sea-surface from above. The amount of the heating depends upon two factors, *viz.* the direct radiation of heat from the sun, and the temperature of the atmosphere. The former factor is the most important one [cf. HELLAND-HANSEN, 1907 b]. The temperature of the atmosphere depends both upon the direct radiation of heat, and on the temperature of the surface-water. The temperature of the air was observed during the different cruises in May; they show, that during the cruise in May, 1901, the air-temperature was, upon the whole, lower (about 0·5° C.) than the temperature of the sea-surface, and in May, 1902, it was considerably lower (about 1° C.), while the relation was the reverse during the cruise in May, 1903; in May, 1904 there was nearly thermic equilibrium between the atmosphere and the sea-surface. The last two cruises were made about a fortnight later in the season, when there is a relatively rapid increase of the air-temperature.

The radiation of heat from the sun thus raises the temperature of both the air and the sea-surface. The heating of the sea-surface, observed in May, 1901 (cf. Fig. 48), was exclusively due to this radiation; the contact with the atmosphere would then lower the temperature of the sea-surface, or, in other words, the latter would raise the air-temperature. In May, 1902, the effect upon the surface-temperature caused by the direct radiation of the sun cannot be seen; the air-temperature was then considerably lower (1 or 2° C.) than during the same days of the preceding year. The air-temperature would then essentially be heated from the sea-surface, this being the primary cause of the variations in the air-temperature. In May, 1903, the air-temperature was considerably higher than the surface-temperature; the sea surface would then be heated by the contact with the atmosphere.

The variations in the air-temperature in winter, before May, depend to a very great extent upon the quantity of heat in the Atlantic water. But in summer the direct radiation of heat from the sun will be the chief cause of the variations in the air-temperatures that are higher than the surface-temperature of the sea and therefore causes an increase of it, this increase is, however, less than that due to the direct radiation. We find accordingly in May the transition between the winter- og summer-conditions; the radiation of heat will then become the primary cause of the variations in the temperature of the air as well as of the sea-surface. But the difference in temperature between the sea-surface and the air has also some effect, reciprocally although it is not great, as there is nearly thermic equilibrium.

When the sea is warmer than the atmosphere, this will be heated by the contact with the surface; the winter-conditions are then prevailing. When the atmosphere is warmer than the sea, it will raise the surface-temperature; the summer-conditions have then been established. Our observations (cf. Figs. 48—52) demonstrate different examples of these relations.

PETTERSSON has found that the fluctuations in the surface-temperature at Ona Lighthouse in spring correspond to quite similar fluctuations in the air-temperature of Sweden, and in the time of blooming of different plants, etc., and he has assumed that the surface-temperature of the water is the primary cause of this correspondence. We have already pointed out (p. 193) that this assumption does not hold good; the surface-temperature at Ona depends upon the radiation of heat, and is also to some extent the effect and not the cause of the air-temperature. PETTERSSON has, however, called attention to the fact that the climate has a marked tendency to keep the same character for periods of some months, and in different parts of large areas (*e. g.* Northern Europe). This is a very important fact, and explains the coincidence, demonstrated by our Fig. 64, between the surface-temperature in May and the air-temperature of the following months; the anomaly of the air-temperature has more or less the same character in June and even in July as it had in May. The surface-temperature in May corresponds to the air-temperature of May, and accordingly also to the air-temperature of the following months. In the same manner as the character of the air-temperature for a couple of months may be predicted by means of the average anomaly of the air-temperature of the preceding months, a prediction of this kind may be based upon the anomaly of the surface-temperature of the sea. Our observations show that this holds good, not only for the water close to the coast, but also for the Atlantic water at the surface far seawards in the Norwegian Sea.

The temperature of the sea-surface is the result of the conditions during some time previously. It is not variable and local to the same extent as the air-temperature. The varying influences of the radiation of the sun and the contact with the atmosphere, will be accumulated during some time, and the mean temperature calculated for the sea-surface gives therefore, so to speak, an average of the varying conditions; we might almost regard the mean surface-temperature as the mean value of the air-temperature and the intensity of radiation for some weeks before; not absolutely, of course, but relatively. We find therefore also a number of characteristic agreements between the mean surface-temperature of the Atlantic water in the Norwegian Sea and such phenomena in Norway as are chiefly influenced by the mean air-temperature.

These relations may be demonstrated by the following figures 65—67. The unbroken line I in fig. 65 represents the mean surface-temperature of the atlantic water along the Sognefjord section, in May of different years (scale to the left). The broken line II (scale to the right) represents the mean growth, in centimetres, of the fir *(Pinus sylvestris)* in eastern Norway for the following years. J. Holmboe [1906] has made a number of measurements of the growth of the fir during the years 1902—1906, at different localities in eastern Norway; the average values of his measurements have been introduced in the figure. The coincidence is remarkably good in all years except in the first one; our observations from May, 1901, seem upon the whole to be somewhat abnormal. But there is also in this case an agreement. The curves show that the variations in the mean surface-temperature of the Atlantic water in May corresponds very closely to the variations in the growth of the Norwegian fir in the next year, *i. e.*

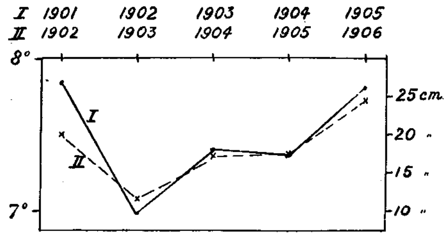


Fig. 65. I Mean Surface-Temperature of Atlantic Water in Sognefjord Section in May.
II Average Growth (in cm.) of Fir in Eastern Norway.

1—1½ year later. HESSELMANN and HOLMBOE have found that the growth of the fir depends upon the climate of the preceding year, when the bud is formed. Fig. 65 shows even as good a coincidence as the mean air-temperature can give, and seems to show that the growth of the fir may be predicted by oceanographic observations in the spring of the previous year.

The curves in Fig. 66 represent:

I. Mean surface-temperature of the Atlantic water along the Sognefjord section in May (scale to the left).

II. Mean anomaly of the air-temperature in Norway in May and June, based upon the observations of 22 meteorological stations (see above p. 194) (scale to the left).

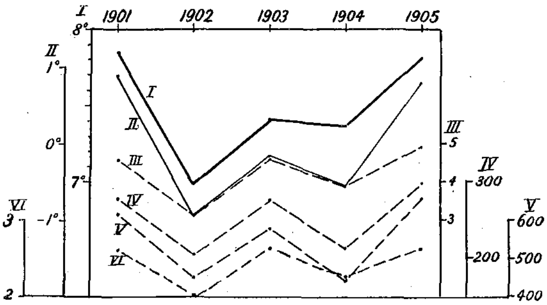


Fig. 66.

III. The total harvest of peas, beans, and lentils in Norway in the same year (scale to the right).

IV. The total harvest of all cereals (scale to the right).

V. The total harvest of potatoes (scale to the right).

VI. The total harvest of hay (scale to the left).

The Curves III—VI are based upon the official Statistic Annual Report of Norway (1). The scales of III—V mean thousands of hectolitres, and that of VI hundreds of tons.

The agreement between the temperatures of water and air and the harvest in Norway is very good. MEINARDUS has found a similar coincidence between the air-temperature and the harvest of Germany [1906]. Our curves show that a high surface-temperature of the Atlantic Current in May gives a good harvest and *vice versa*; but the harvest of course also depends upon the rainfall, etc.

For some kinds of seed the heating of the soil in spring will be of essential importance. The temperature of the soil depends upon the direct radiation of heat from the sun and upon the temperature

(1) *Statistisk Aarbog for Kongeriget Norge* 1901—1905. Christiania.

of the atmosphere, just as the thermic conditions of the sea-surface. We may find approximately the rate of heating of the surface-water, caused by both these factors, by comparing the mean temperature at the surface with that at some intermediate depth (*e. g.* 200 metres). Some time previously the temperature has been almost homogeneous in the Atlantic water down to a depth of, say, 200 metres; the heating of the surface-layers in the spring will produce a difference between the mean temperatures at the surface and at 200 metres. By means of this difference we may estimate the combined effect of the solar radiation and the air-temperature upon the upper layers of the sea as well as upon the surface of the land.

The differences between the mean temperatures of the Atlantic water at the surface and at 200 metres below the surface in the Sognefjord section, have been introduced in Curve I in Fig. 67. Curve II represents the total harvest in Norway of barley, and Curve III the harvest of peas, beans, and lentils. The coincidence is remarkably good; it is perfect for the years 1902—1905; in 1901 the agreement is, as was also seen above, less perfect, partially owing to the fact that the cold waters from below made the mean temperature at 200 metres unusually low.

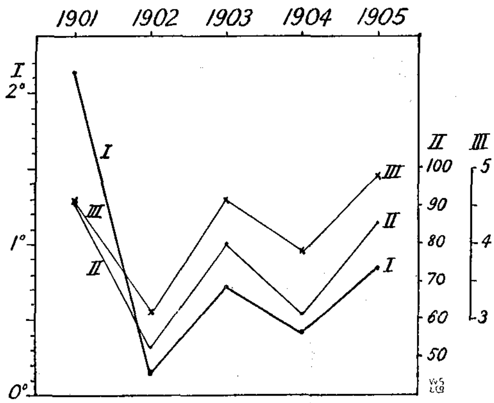


Fig. 67. I Difference between Mean Temp. of Atlantic Water at Surface and at 200 Metres. Sognefj. Section.
II Total harvest in Norway of Barley in Thousands of Hectolitres.
III Ditto of Peas, Beans, and Lentils.

The comparisons made here, prove that in this respect there is a wide field for most interesting research. But as long as there is no more complete observation-material than what has been at our disposal, one has, of course, to be careful and not rely too much upon the conclusions deduced from the observations of such a small number of years, although they may seem very probable and logically well founded.

3. Relation between the Annual Variations in the Temperature of the Atlantic Water and the Growth and Spawning of Food-Fishes.

It is to be expected that variations in the physical conditions of the sea have great influence upon the biological conditions of the various species of fishes living in the sea, and it might therefore also be expected that such variations are the primary cause of the great and hitherto unaccountable fluctuations in the fisheries. It is therefore obvious that it would be of very great importance, not only scientifically but also practically, if the relation between the variations in the physical conditions of the sea and the variations in the biological conditions of the various food-fishes could be discovered. As our investigations have been carried on only for such a small number of years, we have no sufficient observation-material for a thorough study of this important question; but the observations at our disposal give, however, some most interesting indications.

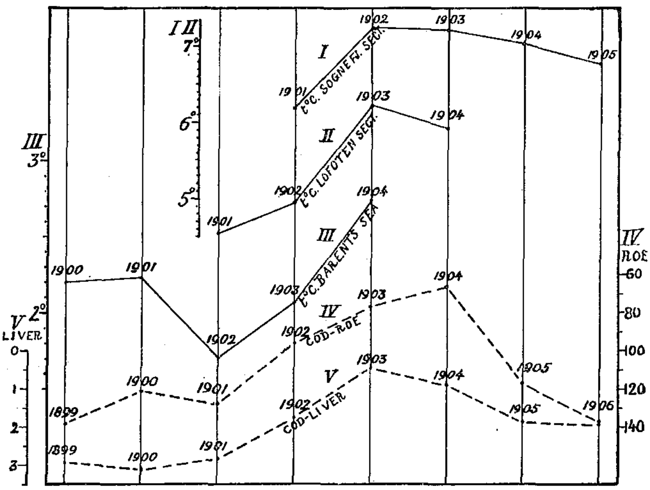


Fig. 68. I & II Mean Temperature of intermediate Atlantic Water in Sognefjord and Lofoten Section.
III Mean Temp. of Barents Sea Stations (cf. Fig. 59).
IV Quantity at Cod-Roe obtained during the Lofoten Fisheries (in Litres per 1000 Fish; scale to the right).
V Quantity of Cod-Liver obtained during the Lofoten Fisheries (in Hectolitres per 1000 Fish; scale to the left).

Fig. 68 demonstrates the relation between the variations in the mean temperature of the Atlantic water in the Sognefjord section (I), in the Lofoten section (II) and in the Barents Sea section (III) for May, 1900 to 1904 and 1905, and the variations in the quantity of *cod-roe* (in litres per 1000 fish, IV) and *cod-liver* (in hecto-litres per 1000 fish, V) obtained during the cod-fisheries ("skrei-fisheries") at Lofoten in the winter and spring subsequent to the years of the Sognefjord section.(1) There is obviously a tendency towards some degree of parallelism between these curves. The quantities of cod-roe, as well as cod-liver, per 1000 fish are comparatively small when the Atlantic water was comparatively warm in the Sognefjord section of the preceding spring, in the Lofoten section of the same spring, and in the Barents Sea section of the following spring, and *vice versa.* The agreement is not very satisfactory between the Barents Sea curve of 1900 and 1901 and the curves IV and V for 1899 and 1900. But it has to be considered that Curve III is not very trustworthy, especially not for those two years, as it is based upon an insufficient number of observations. An exception is also the minimum of cod-roe in 1904, while there was a maximum of temperature in the Lofoten section of the preceding year, and in the Sognefjord section two years earlier(2).

Our curves, Fig. 68, seem on the whole to indicate that there is some kind of relation between the variations in the development of the sexual products as well as the liver of the cod, and the variations in the physical (or chemical) conditions in the water of the Norwegian Sea, as shown by variations in the mean temperature of its Atlantic water. This is naturally no more than might have been expected. During years when the physical (and chemical) conditions are favourable, biologically, it is to be expected that the cod will thrive and get fat, and its liver will become comparatively great. It seems also probable that the sexual products will be well developed and grow ripe early in the season. It is consequently probable that the quantity of cod-roe and cod-liver obtained per 1000 fish during the Lofoten fisheries following upon such favourable years, will be comparatively great, and *vice versa.*

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(1) Cf. *Norges officielle Statistik*, Christiania, for the different years.

(2) We may, however, point out that the volume of Atlantic water with temperature above 8 ° C. in the Sognefjord section, was larger in May, 1903, than in May, 1902 (cf. Figs 49 & 50).

It is, however, not *a priori* probable that the variations in the development of the liver and the sexual products will always coincide. The sexual products are developed and spawned each year while the liver is an organ, which certainly varies much in size, but it remains and has its special function. It is therefore probable that the development of the sexual products is more influenced by temporary variations in the physical conditons every year, while the variations in the liver will not be so sudden, and irregular, but have longer periods of decrease and increase. This seems also to be proved by the fishery statistics in a remarkable manner. It has, however, also to be considered that the figures given by the statistics are much influenced by various factors, especially the weather. If, for instance, the weather is unfavourable during the first part of the fishing season, the greater part of the cod may be fished during the end of the season when many fishes are spent. The result may be that a comparatively small quantity of roe per 1000 fish is obtained, although the sexual products were well developed. It will thus be understood that the values, found by dividing the total quantity of cod-roe obtained, with the total number of cod fished during the Lofoten fisheries each year, cannot demonstrate with any high degree of accuracy the annual variations in the development of the sexual products. But as long as we have no more scientific investigations we have to use the values thus obtained, hoping that they give at least some indication of the great variations, although they may contain many inaccuracies.

The quantity of liver will vary less whether the greater part of the cod is fished early or late in the season, but even this quantity will be somewhat dependent upon such more irregular factors.

The regular spawning season of the Lofoten cod is between February and April. The development of the sexual products which are going to be spawned the following year, begins after the spawning. The cause of the annual variations in the quantity of cod-roe cannot therefore probably occur more than from $^3/_4$ to 1 year in advance. It is consequently highly improbable that it should be the same cause which created the high temperature of the Atlantic water in the southern Norwegian Sea in May, 1902 and 1903, and independently of this condition produced the reduction in the quantity of cod-roe (and cod-liver) in 1903 and 1904.

We may mention the Lofoten fisheries in 1903 as a striking example of the extent to which the growth of the fish and the development of its sexual organs depend upon the conditions in the sea during the preceding year. The biological conditions were evidently quite abnormal in the northern parts of the Norwegian Sea during the winter and spring of that year. During the early part of the fishing season there was a universal lack of fish of all kinds along the northern Norwegian coasts, and as Dr. HJORT states, "when the cod did finally arrive (in Lofoten), the appearance they presented was truly a miserable one". Already in the same year, 1903, he wrote the following about his investigations of the cod in Lofoten and Finmark: "Besides the exceptionally poor quality of liver, which sank in sea-water, the scarcely developed sexual organs struck me as remarkable. Not only were the ovaries imperfectly developed, but the extremely small size of the eggs in March showed a development that is ordinarily present in December or the beginning of January." It is consequently probable that the cod has had very unfavourable biological conditions in the sea during the preceding year. This coincides exactly with the unusually high temperature of the Atlantic water in the Sognefjord section of the preceding spring, May, 1902, and in the Lofoten section of the same spring, May, 1903.

The Norwegian fishery-researches carried on under Dr. HJORT's leadership, in connection with the International Researches during recent years have led to most important discoveries as to the variations in the spawning and growth of the ordinary food-fishes. By comparing the results obtained, with the variations in the mean temperature of the Atlantic water in the Norwegian Sea we find almost in every respect remarkable agreement.

We may as an example take the variations in the spawning and growth of the haddock (*Gadus aeglefinus*). The International Researches prove that this fish spawns in the northern area of the North Sea in deepish water. This is consequently near the region of our Sognefjord section. The spawning season is in the early spring. By determining the age of a great number of fishes in different catches and from different regions of the North Sea and Skagerack it was discovered that by far the greatest quantity of haddock found in these regions in 1903 to 1907, had been born in special years only, while comparatively very few individuals had been born in the other years. Helland-Hansen has worked up the large number of haddock-measurements made by the English and German research-steamers in the North Sea, and has, for instance, found the following values of the average number of individuals per hour of trawling:

	In 1903	1904	1905	1906	
Small Haddock	30	8	5	12	individuals
Extra Small —	11	4	12	51	—

The market-group "Extra Small" consists of individuals which are 1 and 2 years old, and the individuals belonging to the market-group "Small" are 2 and 3 years old. From the above average numbers of individuals in the catches it will thus be seen that in the North Sea there were very few individuals born in 1902 and 1903, but many that had been born in 1901 and 1904 [HELLAND-HANSEN, 1909]. In Fig. 69 Curve I represents the mean temperature of the Atlantic water in the Sognefjord section, in May, and Curve II the average number of Small Haddock caught per hour during the trawling experiments of the research-steamers in the North Sea. We have only observations from 4 years for comparison; but the coincidence within these years is striking.

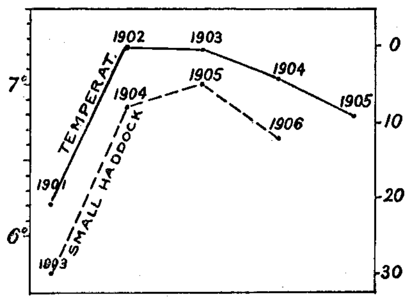

Fig. 69.

At the same time it was found that the growth of the haddock was much slower in the years with poor spawning, *e. g.* haddocks in 1902 and 1903 were smaller than haddocks of the same age in 1905 and 1906.

The above results as regards the variations in the number of "small haddocks" are perfectly confirmed by the English official statistics giving the quantities of haddocks landed at English ports. Great quantities of "small haddock" was landed in 1903, while in 1904 the quantity was very small, and in 1905 still smaller [cf. HJORT 1908,

Fig. 17, p. 33, and HELLAND-HANSEN, 1909, Fig. 30, pp. 43—44]. This proves that the number of haddocks born had been small in 1902, and still smaller in 1903.

The above facts agree in a remarkable manner with the variations in the mean temperature of the intermediate Atlantic water in the Sognefjord section. A comparatively high mean temperature of the Atlantic water coincides with a poor spawning season of the haddock, while lower mean temperatures coincide with the two good spawning seasons. But what is almost still more remarkable is that the variations in the spawning of the haddock in the North Sea coincide with the variations in the quantity of cod-roe (per 1000 fish) fished in Lofoten during the following winter and spring (cf. the resemblance between the curve of small haddock, in Fig. 69, and Curve IV in Fig. 68). This fact seems to indicate that the two kinds of variations have the same cause, the effect of which is felt one year earlier in the North Sea than farther north, in Lofoten.

It is a noteworthy fact that the curve in Fig. 69 indicates a minimum, of haddock born, in 1903, as Curve IV, Fig. 68, indicates a minimum of cod-roe the following year in Lofoten, although the mean temperature of the Atlantic water in the Sognefjord section was higher in 1902 than in 1903. But it is probable that there has been a maximum in the relative temperature of the Atlantic water at some time between May, 1902, and May, 1903, and this time may have been the important one for the development of the fish. We have also pointed out, that there was more Atlantic water with temperature above 8 ° C. in the Sognefjord section in May, 1903, than in May, 1902 (cf. p. 205, footnote); and it is possible that this may indicate some difference of importance during the preceding year. It is also noteworthy that there was less coast-water along the Norwegian coast in May, 1903, than in May, 1904 (cf. Chap. VIII).

Other cod-fishes in the North Sea, which have been examined, show similar variations in their spawning and growth. We may also mention the *herring*, which is mentioned in No. 1 of this Report ["Review of Norwegian Fishery Investigations 1900—1908"].

The quantities of Norwegian maties (fat-herring) caught in the summer of 1907, were composed of two year-classes, $2^1/_2$ and $3^1/_2$ years of age, *i. e.* they had been born in 1905 and 1904. In the summer of 1908 the preponderating majority of maties were $4^1/_2$ years old, *i. e.* they had been born in 1904. This proves that the $4^1/_2$ years old herring had not gone to the "large-herring" ("storsild"), and if there had been herrings of this age in 1907, they would have been caught with the other year-classes of maties. But both in 1907 and in 1908, exceedingly few individuals born in 1903 were found. This proves that the spawning of the herring has been very poor that year, just like that of the haddock, which coincides with the high mean temperature of the Atlantic water. We have unfortunately no observations from which we can conclude how the spawning of the herring was in 1902. The above mentioned observations of 1907 and 1908, seem to indicate that the spawning of the herring was not so good in 1905 as in 1904; although the mean temperature of the Atlantic water in the Sognefjord section was lower in May, 1905, than in May, 1904. We pointed out above (p. 205) that there was more Atlantic water with temperatures above 8° C. in the Sognefjord section in May, 1905, than in May, 1904, and this might indicate some difference of importance. It is possible that other factors, *e. g.* the *coast-water,* are of importance. There was much coast-water in May, 1904, but less in May, 1905, and much less in May, 1903; it will be shown in Chap. VIII, that there is evidently a connection between the quantity of coast-water and the catches of small herring. It is also noteworthy that unusually little *Arctic water*, with salinity below 34·90 ‰, was observed in the Sognefjord section of May, 1905 (cf. Fig. 52), while there was much in May, 1904.

There are great variations in the time when the Lofoten cod comes to the banks, and when the main body of it is caught in the different years. We have, for instance, mentioned that the cod arrived exceptionally late in 1903, and was in a very poor condition.

As the cod comes to the Lofoten Banks for the purpose of spawning, it might seem probable that the time of its arrival is influenced by the development of its sexual organs. It is therefore probable that in years when the biological conditions in the sea have been favourable and the sexual products have been early developed, the cod will arrive relatively early, and *vice versa.* We have pointed out above that the annual variations in the mean temperature of the Atlantic water probably coincides with variations in the biological conditions of the sea, as they are also followed by variations in the air-temperature. If this be correct, it might thus be probable that there is some kind of resemblance between the variations in the temperature of the Atlantic water, as well as the air, and the variations in the time of arrival of the cod at the Lofoten Banks.

In order to study this question we have calculated for a series of years the proportion between cod caught in Lofoten before March, 15, and the total quantity caught during the whole of the fishing season (end of January to end of April). The superintendant of the Lofoten fisheries at Svolvær has for a great number of years made observations of the air-temperature at noon, during the fishing season, and we have made use of the average of all these temperature-observations. The curves in Fig. 70 represent:

I. The mean temperature of the intermediate Atlantic water in the Sognefjord section, in May.

II. The mean air-temperature at noon, observed at Svolvær, in Lofoten, during the fishing season.

III. The number of cod (in millions) caught before March, 15.

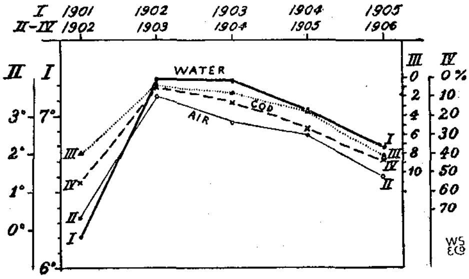

Fig. 70.

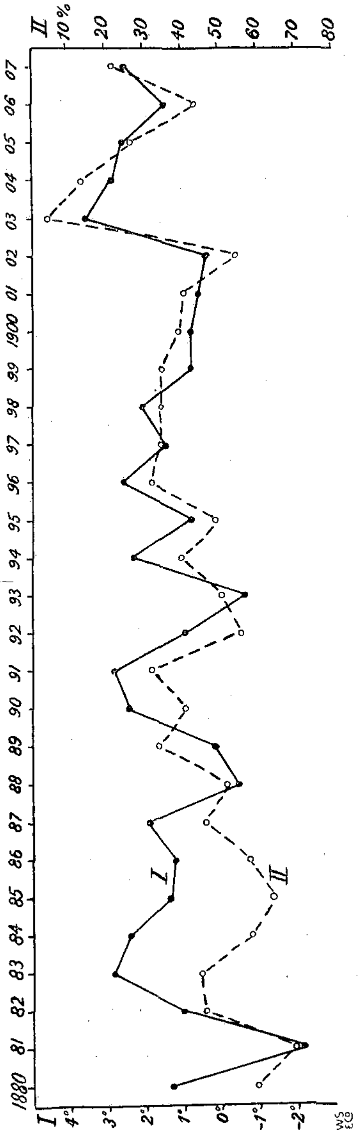

Fig. 71. I Mean Air-Temperature at noon in Svolvær, from end of January to end of April, 1880—1907.
II Percentage of Cod caught before March 15, in proportion to Total Quantity.

IV. The percentage of cod caught before March 15, in proportion to the total quantity of the whole season.

Here, too, we have a very good coincidence. It is noteworthy that Curve II, representing the air-temperature at Svolvær, agrees very well with the Curve (I) of the mean temperature of the intermediate Atlantic water of the Sognefjord section in May of the preceding year. It will be seen from the tables on pp. 177, 182 that the mean intermediate temperature in several cases show the same fluctuations as the figures representing the total quantity of heat in the Atlantic water; this will always be the case when there are not too great differences in the volume of water. We might therefore expect to find some agreement between the annual variations in the mean air-temperature at Svolvær, and the variations in the percentage of cod caught before March 15, in proportion to the total quantity caught during the whole season. This holds good, as is demonstrated by Fig. 71. Curve I (unbroken line) represents the mean air-temperature at Svolvær, from the end of January to the end of April, for each year from 1880 to 1907; Curve II (broken line) represents the percentage of cod caught in the first half of the season (before March 15). The curves include 28 years; there is a good agreement in 25 of these 28 cases (*i. e.* in 89 %), and in many of them even a perfect parallelism. It is probable that a still better agreement would have been found if we had possessed observation-material for comparing the percentage of cod directly with the temperature of the Atlantic water.

We have pointed out above the probability of an agreement between the variations in the quantities of *cod-liver* and *cod-roe*, per 1000 fish, caught each year in Lofoten, and the yearly variations in the mean (intermediate) temperature of the Atlantic water, in the Sognefjord section of the preceding spring and in the Lofoten section of the same spring. If this be correct, and if to some extent there is an agreement between the mean air-temperature in Norway in the winter and the temperature of the Atlantic water, we may expect to find, at least some kind of agreement between the variations in the air-temperature and the said variations in the quantities of cod-liver and cod-roe. As we have observations of the temperature of the Atlantic water in the Sognefjord section only for five years, while we have meteorological observations from Norway, as well as statistics of the Lofoten fisheries, for a much longer series of years, we may

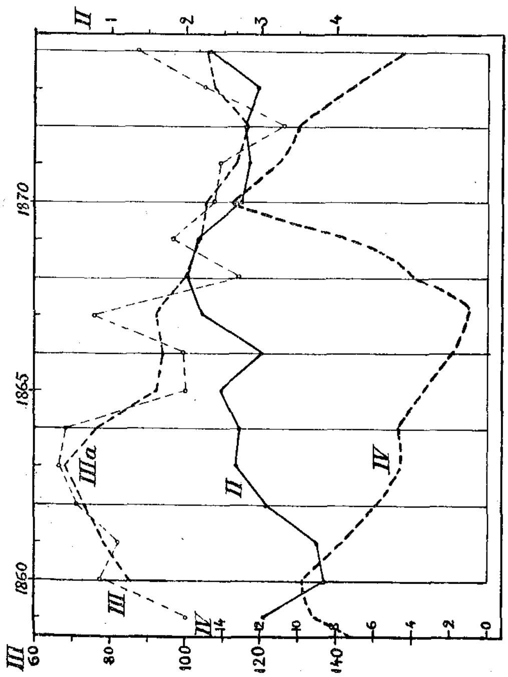

Fig. 72. The Numbers of the Curves, the same as in Fig. 73.

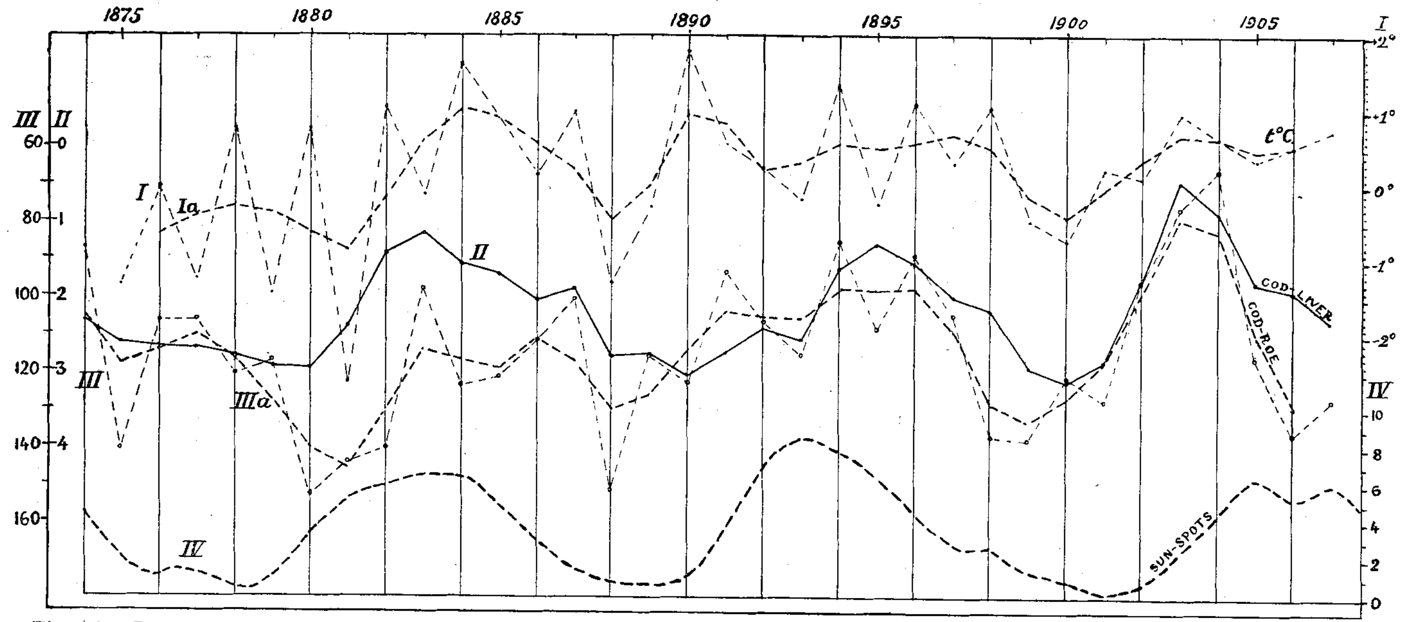

Fig. 73. I Anomaly of Mean Air-Temperature from Nov. 1 to Apr. 30, at Ona Lighthouse, 1875—1907. I *a* is the Average-Curve (scale to the right).

II Quantity of Cood-Liver, in Hecto-litres per 1000 Fish, Lofoten Fisheries.

III Quantity of Cod-Roe, in Litres per 1000 Fish, Lofoten Fisheries. III *a* is the Average Curve (scale of II & III to the left).

IV Variations in the Number of Sun-Spots (scale, giving the relative numbers, to the right).

use these in order to examine whether they confirm the agreement we have found between the variations in the temperature of the Atlantic water and the fisheries. But as the air-temperature evidently depends upon the quantity of heat stored in the Atlantic water, and not merely on its mean temperature, we cannot expect the conformity between the two kinds of variations to be very good, except in years when there has been no great differences in the volume of the Atlantic water.

The broken-lined Curve I, in Fig. 73, represents the variations in the *anomaly*, of the mean *air-temperature* (scale to the right) at Ona Lighthouse, from November 1st to April 30th, for the years between November, 1874, and April, 1907. The numbers of the years are so arranged that *e. g.* 1875 means November, 1874, to April, 1875, &c.

The curve of the mean air-temperature at 22 meteorological stations in Norway in the same months (Nov.—Apr.) is quite similar to this curve, only the variations are somewhat greater and they seem to be more influenced by some continental factor.

Curve II (Figs. 72 & 73) represents the quantity of *cod-liver*, in hecto-litres per 1000 fish (scale to the left) and Curve III the quantity of *cod-roe*, in litres per 1000 fish (scale to the left), caught in Lofoten in the years 1874—1907.

As the Curve I (of the mean air-temperature) and Curve III (of the quantity of cod-roe) show very great yearly variations we have constructed average-curves, by introducing for each year the mean of the means between the value for that year and those for the preceding and the following years, computed according to the formula $\frac{a+b}{4}+\frac{b+c}{4}$. We have thus obtained the curves Ia and IIIa.

There is a greater resemblance between the three curves I a, II, and III a, than we had expected that there could be, considering the deficiency of the observations on which they are based and the inaccuracy of the methods used; because Curve I can only give an approximate indication of the variations in the mean temperature of the Atlantic water, and the curves II and III give no accurate representation of the variations in the actual development of the liver and roe of the cod in the different years, the quantities caught depending much on various more or lees accidental factors, as was mentioned above. Nevertheless, at least the great periods coincide very nearly in all three curves, minimum of temperature falling on maximum of liver and roe, and maximum of temperature on minimum of liver and roe. The most cospicuous exception is the year 1890, when there was an actual maximum of temperature coinciding with a maximum of liver and a secondary maximum of roe. We see that the temperature of that year, and partly also that of 1891, breaks the regular periodicity of the temperature curve, and we may assume that some special factor has had exceptionally great influence that year. We also see that the high temperatures of 1906 and 1907, do not agree well with the comparatively great quantities of cod-liver and especially cod-roe; but we have seen above that the high air-temperature of the winter 1905—06, was due to a great quantity of heat stored in the Atlantic water which had a great volume, while its mean-temperature was lower than the three preceding years (cf. Figs. 59, 60) (1).

It is probable that if we had actually had the mean temperatures of the Atlantic water in the various years in stead of that of the air at Ona, and if the relative quantities of cod-liver and cod-roe (pr. 1000 fish) had been determined by more accurate methods, in order to show the real condition of the cod, the conformity between the curves would have been still better. But our curves, even as they are, confirm the correctness of our conclusion, drawn from the observations of five years (1901—1905), that there is a close relation between the yearly variations in the conditions of the Lofoten cod (as well as some other food-fishes)—and also the time of its arrival at the banks—and the yearly variations in the mean temperature of the Atlantic water, as found in the Sognefjord section of May of the preceding year. And on the other hand these curves also confirm our conclusion that there is a close relation between the yearly variations in the heat of the Atlantic water, as found in the Sognefjord section in May, and

(1) We mentioned above (p. 210) that the spawning of the herring in the North Sea, seems to have been poor in 1905 while it was good in 1904, which appears to indicate more favourable biological conditions in 1904 than in 1905. We should then expect the cod in Lofoten to have been in a poorer condition in 1906 than in 1905; but this does not appear to have been the case. But we pointed out that there may probable be other factors (*e. g.* the coast-water) that influence the spawning of the herring.

the character of the air-temperature in Norway in the following winter.

Agreement with the Periods of the Sun-Spots. The curve representing the variations in the quantity of cod-liver per 1000 fish struck us as demonstrating remarkably regular periods, that have some similarity to the *periods of the sun-spots*, although according to the observations at our disposal, they might seem slightly shorter. The broken-lined Curve IV in Fig. 73, represents the secular variations in the number of sun-spots (the scale showing the relative numbers is to the right). [According to Rud. Wolf and Dr. Wolfer]. We have computed the quantities of cod-liver and cod-roe per 1000 fish for the *Lofoten Fisheries* for all years from which we could obtain observations, which is after 1859 (1); in Fig. 72 we have introduced the curves for these quantities and for the sun-spots for the years previous to those of Fig. 73. With the exception of the first part of the time, before 1875, when the fishery statistics seem to be less trustworthy, there is a fairly good agreement between the three curves, especially between the curve of the cod-liver and the curve of the sun-spots, the maximum of cod-liver having a marked tendency to coincide with minimum of sun-spots, although the three periods which are most distinct in the cod-liver, *viz.* between 1880 and 1907, seem to be slightly shorter (perhaps 10 years?) than the periods of the sun-spots. How this would be for a greater number of years, we cannot say. Fig. 72 indicates that in 1860 a maximum of cod-liver coincided with a maximum of sun-spots, but the statistics for this early time seem to be of somewhat doubtful value, as is also proved by the two curves for cod-liver and cod-roe which, especially during the period from 1859 to 1870, diverge from each other in a manner which is at variance with the curves for later years when the statistical material is more trustworthy. We assume that the curve of the cod-liver is the more reliable one of the two, as it shows more resemblance in shape to later years.

(1) The observations for 1859—1865 are taken from the report on the Lofoten fishery of 1865, in *Bilag til Departements-Tidende No. 31 for 1865;* for 1865 to 1881 from *Retrospective Tables* in *Norwegian Statistics* C. No. 9. *Statistics of the Sea Fisheries of Norway, 1881*, Christiania 1883; for later years *Norges officielle Statistik, Tabeller vedk. Norges Fiskerier.* Christiania.

Fig. 73 also demonstrates a similarity between the periods of the sun-spots and the periods in the winter-temperature of Norway or at Ona Lighthouse (Curve I a).

Trustworthy observations from a greater number of years would be desirable in order to draw certain conclusions; but our curves, in Fig. 73, evidently prove the existence of a relation between the different kinds of variations mentioned, and probably also between the variations of the sun-spots and the variations in the Atlantic Current.

It has been known that there is a connection between the periods of the sun-spots and the variations of several other terrestrial phenomena. *E. g.* a tendency has been found towards a coincidence between the maxima of sun-spots and comparatively warm springs in northern Europe [cf. ARRHENIUS, 1903, p. 145]; while KÖPPEN has shown that in the Tropics the *minima* of the mean annual temperature occur about a year before the *maxima* of sun-spots. A relation between the periods of the sun-spots and the variations of different biological phenomena on land has also been observed, *e. g.* an earlier occurrence of the blooming of various plants, and also a better vintage in years with numerous sun-spots, and *vice versa.* It has been pointed out [cf. ARRHENIUS, 1903, p. 146] that these variations might be explained by an increase of the barometric minima in the northern Atlantic during the first months of years with numerous sun-spots, and that in this manner prevailing southerly winds during the spring are created in northern Europe. These barometric minima in the Atlantic may be due to variations in the Gulf Stream, and ARRHENIUS thinks that the Gulf Stream may be increased by the greater frequency of cyclones in the region of the Antilles during years with numerous sun-spots. We think that our investigations prove that the Atlantic Current (Gulf Stream) moves so slowly that an explanation such as this is not quite satisfactory; but we consider it probable that the periodicity in the sun-spots, or rather in the energy received from the sun, causes variations in the oceanic currents (either directly or indirectly, through the atmosphere). Our investigations prove the probability that the variations in the Norwegian Atlantic Current cause again variations in the winter-temperature of Norway, in the following winter and spring, and also variations in the fisheries.

The relation between these different kinds of variations is, however, very complicated, and will require special investigations which we have to postpone for our later publication on the Hydrosphere and Atmosphere.(1)

Relation between the Variations in the Spawning (Cod-Roe) and the Quantity of Cod in the Sea.

We have found that the variations in the biological conditions in the Norwegian Sea, due to the variations in the water of the Atlantic Current, cause variations in the development of the sexual products, and consequently in the spawning.(2) If this be correct, we must conclude that in this manner variations are also caused in the quantity of fish living in the sea; and after a certain number of years, which the fish requires for reaching the mature age, the above mentioned variations ought consequently to be repeated, to some extent, in the total number of fish caught. The statistics prove that our assumptions hold good also on this point. Fig. 74 is the result of our investigations. DAMAS [1909] has found that the quantities of Lofoten cod, coming in from the sea to the banks for the purpose of spawning, are mature fish of a great many year classes, chiefly from 7 to 12 years old. We cannot therefore expect to find that the successful or unsuccessful spawning of a certain year will have a very conspicuous influence upon the quantity of cod caught after a certain number of years; but we may expect that the average state of the spawning during a number of years

(1) It might seem probable that variations in the sun directly influence the biological conditions in the sea. It has been found that the formation of clouds in the Atmoshere varies with the number of sun-spots. It might therefore be possible that during maxima of sun-spots and maxima of clouds, the biological conditions in the sea were made less favourable, as the amount of sun-light reaching the sea-surface might be reduced. But if this be the chief cause of the variations in the biological conditions we must expect that the unfavourable conditions would occur simultaneously in all regions. We have, however, found that they occur one year later in Lofoten than in the North Sea, which proves that they follow the moving water-masses, and are not directly due to variations in the sun-light. This is also proved by the fact that the maxima of sun-spots coincide with favourable biological conditions (for the plants) on land, and with unfavourable biological conditions in the Norwegian Sea.

(2) It is probable that the spawning will be most successful in the years when the sexual products are well developed and the spawning occurs at the normal time.

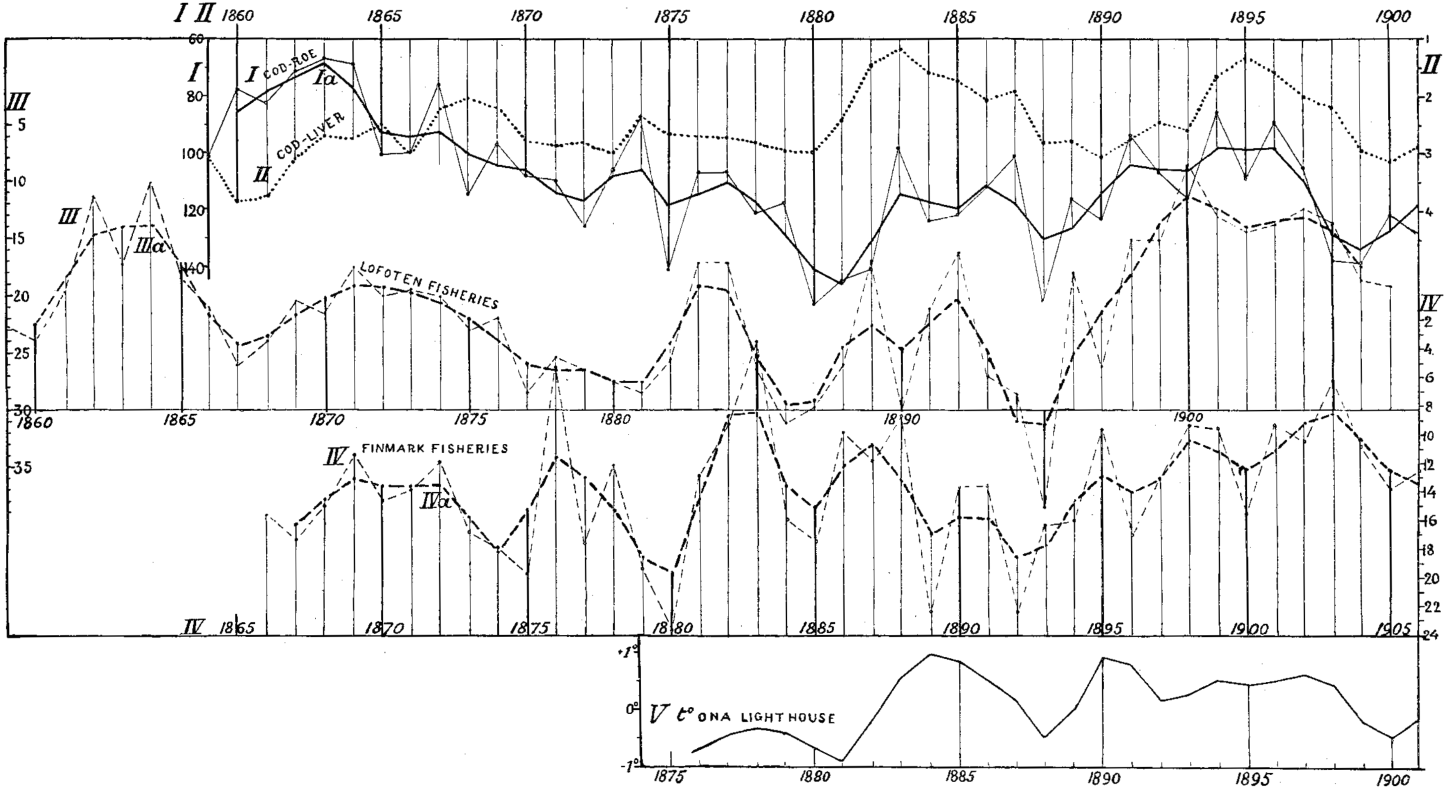

Fig. 74. I Quantity of Cod-Roe, in Litres per 1000 Fish, Lofoten Fisheries, 1859—1901. I *a* Average-Curve.
II Quantity of Cod-Liver, in Hecto-litres per 1000 Fish, Lofoten Fisheries (scale to the right).
III Total Number of Cod, in Millions, caught during the Lofoten Fisheries, 1859—1907 (scale to the left). III *a* Average-Curve.
IV Total Number of Cod, in Millions, caught during the Finmark Fisheries, 1866—1906 (scale to the right). IV *a* Average-Curve.
V Average-Curve of Mean Air-Temperature (Nov. 1—Apr. 30) at Ona Lighthouse (cf. Fig. 73, I a).

will influence greatly the quantity of cod in the sea, and consequently also the quantity of fish coming to Lofoten. Our average-curve Ia of the quantity of cod-roe per 1000 fish (Curve IIIa in Fig. 73) may to some extent represent the average state of the spawning during three years at a time (see above). It might be more difficult to find a trustworthy method for measuring the quantity of cod in the sea; the total number of cod fished every year depends naturally much upon the quantity of fish existent in the sea at the time, but it is also influenced by various accidental circumstances, *e. g.* the weather during the fishing season, the migrations of the fish, and the time when it comes to the banks, whether early or late, &c. But having no better observations we have to use these numbers. It might be expected that the number of cod fished per man, would be more accurate. We have tried both methods but the two curves show no difference of importance; we have therefore used the total number of fish caught during the Lofoten fisheries every year, for the construction of our curve III (IIIa is the average-curve; cf. above p. 214).

As the age of the Lofoten cod is chiefly 7 years and more, we have moved the curve 7 years to the left in relation to the curve of the quantity of cod-roe (Curve I), so that, for instance, the number of cod caught in 1907 comes under the relative quantity of cod-roe in 1900. The resemblance between the variations shown by the curves seems to us to be remarkably good, considering the inaccurate methods used. The agreement is especially good after 1875 of the cod-roe, corresponding to 1882 of the total number of fish caught. Before that time the curves, especially the curve of the cod-roe, show certain peculiarities which are probably due to inaccurate statistics or other circumstances. According to the curve the cod seems to have had remarkably little roe during the years from 1859 to 1874, and worst is it in the first years, before 1865, when probably the statistics are less trustworthy. The curves of the cod-liver (II) agrees here better with the curve of the quantity of fish, and may possibly give a more correct representation of the variations in the biological conditions of the cod. The statistics of the cod-liver may possibly have been better than the statistics of the cod-roe for those years; but even they seem somewhat doubtful especially in the first years. They indicate that before 1862 the cod had more liver than ever since that time, while at the same time the cod-roe should have been unusually small, in 1863 there should even have been an absolute minimum of cod-roe, per 1000 fish, equalled only by that of 1904.

This is hardly possible, but it is difficult to say which values are most at fault, whether those obtained from the statistics of the cod-roe, or those from the statistics of the liver.

According to DAMAS(1) the main quantity of the cods of the *Finmark Fisheries* (the Capelin Fisheries) are from 4 to 6 years old. If we assume that this cod has chiefly been born on the banks of Lofoten and Vesteraalen it seems probable that there is some kind of agreement between the fluctuations in the spawning (or in the development of cod-roe) in Lofoten, and the fluctuations in the Finmark capelin fisheries about five years later. Curve IV (Fig. 74) gives the total number of cod fished every year in Finmark, and seems to indicate an agreement in the fluctuations, of the kind mentioned; but it has to be considered that the Finmark fisheries are evidently also greatly dependent on other and more local coditions (especially the migrations of the fish), so that the agreement cannot be expected to be very perfect. The two curves, III and IV, indicate moreover that there is some kind of relation between the fluctuations in the Finmark fisheries and in the Lofoten fisheries about two years later(2).

We have added in Fig. 74, the average-curve (V) of the air-temperature at Ona Lighthouse (cf. Fig. 73), in order to show how well the fluctuations of this curve agree with the fluctuations of the curve of the Lofoten-fisheries 7 years later, and the curve of the Finmark fisheries 5 years later.

After the preceding sheets had been printed we have obtained the following data concerning the *Lofoten Fisheries* of the two last years:

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(1) Cf. This *Report*, No. 1, p. 151.

(2) Dr. BRUNCHORST [1899] thought that he had found an agreement between the fluctuations in the Finmark fisheries and in the Lofoten fisheries of the following year. We think that on the whole they agree better if we take an interval of two years as is proved by our curves. This is also in better conformity with DAMAS'S determinations of the ages of the cods of the two fisheries.

	Total Number of Cod caught.	Cod-Roe. Litres per 1000 Fish.	Cod-Liver. Hecto-litres per 1000 Fish.
1908	13,300,000	149	3·63
1909	16,800,000	122	Above 3(1)

The cod has consequently been in very good condition (with well developed liver and sexual organs) in both years. This is just what might be expected, as we are approaching a minimum of sun-spots (next year). The total numbers of cod caught are smaller than in 1906 and 1907. This agrees with the differences in the relative quantity of cod-roe 7 years earlier (see the average-curve Fig. 74, Ia, and Fig. 73, IIIa).

The mean anomaly of the air-temperature at Ona Lighthouse for November 1st, 1907, to April 30th, 1908, was + 1·05° C. which is higher than in 1906 and 1907. For November, 1908, to April, 1909, it was + 0·5° C. This does not agree with the approaching minimum of sun-spots, nor with the great relative quantities of cod-roe and cod-liver in 1908. The air-temperature of the last years has evidently been a similar exception as we found in the years about 1899 (cf. p. 215), but it looks as if the comparatively low temperature of this spring (1909) is more in accordance with the rule. The mean anomaly for Febr.—Apr., 1909, was — 1·0° C., and May will probably be still colder.

We began by finding a striking similarity between the variations in the temperature (and quantity) of the Atlantic water in the Sognefjord section and the variations in the winter-temperature of Norway (in the following winter), in the growth and spawning of fish in the North Sea in the same year, in Lofoten in the following year, in the distribution of the ice in the Barents Sea two years later, &c. &c. Although the comformity between the different kinds of variations were in many cases remarkably perfect, one cannot draw any certain conclusions from observations of such a small number of years. But after having now, by various methods, extended our investigations over a much longer time, nearly fifty years, and having found the correctness of our conclusions confirmed, more or less, everywhere, they have become considerably better founded. The coincidence between all the various facts mentioned, of so widely different nature and taken from so different sources, is striking, and it can no more be ignored as merely accidental.

As the variations in the mean temperature of the Atlantic water in the Sognefjord section are antecedent to most of the other varia-

(1) The exact quantity has not yet been computed, but the fish was fat, and there was certainly more than 3 hecto-litres liver per 1000 cod.

tions we must assume that either the variation in the sea temperature is the primary cause of the other variations, or it is an indicator of variations in the physical or chemical conditions of the sea which are the primary cause.

It is easy to understand that even small variations in the sea temperature may have an appreciable effect upon the temperature of the atmosphere, as was pointed out above. But it is more difficult to understand that such comparatively small changes should directly have so marked an effect upon the growth and spawning of fish, especially considering that this effect is conspicuous in so widely separated areas as the North Sea and the sea off northern Norway (and probably even in the Barents Sea), where the thermic conditions differ so much. It is not probable that the food-fishes which migrate so widely, should be so dependent on slight variations in the temperature of the water in which they live. It is then more probable that it is the plankton being the food of the fishes, which is dependent on the water-temperature, but even this does not to us seem to be a satisfactory explanation of the facts. We are rather inclined to believe that the variations in temperature are accompanied by variations in other physical or chemical conditions of the Atlantic water, and that there may to some extent be variations in the kinds of water conveyed by the Atlantic Current. That such variations actually occur, seem, for instance, to be indicated by the sudden occurrence of *Biddulphia sinensis* along the coasts of the North Sea. This tropical plankton form which had previously never been observed in the northern seas, was suddenly after October of the famous year 1903, found in great quantities in the sea along the coasts of Jutland, in Skagerack and Kattegat, and along the coast of Norway. It had not existed in the North Sea, at least not in any quantity, as late as August, 1903 [OSTENFELD, 1908]. This indicates the possibility of remarkable variations in the kind of water carried by the Atlantic Current.

We know at present nothing about the causes of the above-mentioned variations in the temperature and volume of the Atlantic water carried into the Norwegian Sea. These causes have probably, to some extent, to be looked for in the Atlantic Ocean and depend on the physical conditions there. We consider it, however, to be probable (cf. above, p. 185) that there are annual variations in the *East Iceland Arctic Current*, and that these variations may have some influence upon the character and quantity of Atlantic water carried in through the Færoe-Shetland Channel. It is possible, for instance, that a comparatively great quantity of *Arctic water* carried along the northern slope of the Færoe Platform into the mouth of the Færoe-Shetland Channel might, to some extent, check the Atlantic current, and by partial intermixture (*e. g.* by the vortex-movements in the Channel) it may make the Atlantic water somewhat colder; while a comparatively small quantity of Arctic water carried into the Channel will have less effect upon the Atlantic water. It is, however, possible that this Arctic water possesses physical or chemical properties which are of great importance for the development of the plankton life, and thereby also for the growth of fishes [cf. NANSEN, 1902, pp. 422—425]. If this be correct, it is to be expected that an increased amount of Arctic water carried into contact with the Atlantic water in the region of the Færoe-Shetland Channel will improve the biological conditions of the food-fishes, during the same season in the region of the North Sea, and one year later near Lofoten; at the same time it cools the waters of the Atlantic Current, and also lowers the temperature of Norway during the following winter. We have pointed out above (p. 185) that the observations may possibly indicate variations in the quantity of Arctic water, carried by the East Iceland Current, and that these variations (perhaps with the exception of 1905) seem to coincide with the variations observed in the temperature of the Atlantic water in the Sognefjord section of May. But the observations in the Iceland Current are only from a few years, and no certain conclusions can be drawn from them.

It may be of some interest in this connection that MEINARDUS [1906] thinks that he has found a coincidence between the periods in the occurrence of ice near Iceland and the periods of the sun-spots. We might expect this, if the assumption be right that the variations in the Iceland Current has some connection with the variations in the temperature of the Atlantic water of the Sognefjord section; because the variations in the occurrence of ice near Iceland may perhaps to some extent be connected with the variations in the East Iceland Current.

There is, however, this difficulty that if the coincidence we believe to have found between the variations in the sun-spots and the variations in the temperature of the Norwegian Atlantic Current, in the cod liver, &c., be correct, there ought to have been approximately a coincidence between the maxima of ice near Iceland and the minima of sun-spots, while MEINARDUS believes that the has found a coincidence between the maxima of the two. But during the latter half of last century (after 1846) there is very little similarity between the curve of the sun-spots and his curve of the occurrence of ice near Iceland. In 1856, 1866 to 1868, and 1886 and 1887 maxima of ice almost coincide with the minima of sun-spots or rather are a year or two ahead of them [cf. MEINARDUS, 1906, Pl. 7) as they ought to be in order to agree with our conclusions. But the observation-material is too inaccurate and of too accidental a nature for allowing us to say much on this point at present. It has also to be considered that the distribution of the ice in the Iceland Sea is not only influenced by the variations in the Polar and Arctic currents but also by various other factors, especially the winds, &c.

As the river-water carries into the sea substances that are of importance for its plankton life, it is probable that the variations in the quantity of the *coast-water* (cf. Chap. VIII) have influence upon the biological conditions of the sea, and that they consequently also are of some importance for the growth of the food-fishes, and the development of their sexual organs.

But there is no time for going further into the details of these complicated questions here. We shall return to them in a later publication.

Before we leave the subject of the variation in the biological conditions in the sea, we may add a few words about the exceptionally unfavourable year 1903, when there were evidently quite abnormal conditions in the Norwegian Sea. Our Curve II, in Fig. 73, shows an absolute minimum of cod-liver, per 1000 fish, in Lofoten that spring; there was also a very small relative quantity of cod-roe, but the minimum seems to have occurred the following year. As Dr. HJORT has pointed out [1907, 1908] several phenomena indicate that during the same winter there were quite abnormal conditions in the sea even still farther north and in the Barents Sea. Both seals (*Phoca groenlandica*) and white whales (*Delphinapterus leucas*), which usually remain in the Arctic seas, came far south along the coast of Norway, in some instances as far as the Shetlands, Skagerack, and white wales were even seen in the inner end of the Christiania Fjord. Great numbers of the Greenland seal swarmed on the coasts of Finmark and Lofoten and Vesteraalen, where they are very rarely seen, and frightened the fishermen, who thought that they were the cause of the scarcity of fish. Dr. HJORT also mentions that "thousands of dead sea-birds (guillemots, *Uria brünnichii*) said to be in a completely emaciated condition, were washed ashore on the Murman coast".

These facts might seem to be inconsistent with our assumption that the variations in the physical conditions of the Barents Sea, the usual home of the said seals, follow about one year later than the corresponding variations in the sea off Lofoten. We think, however, that there was probably that year a remarkable coincidence of unfavourable circumstances which had more or less different causes. Unfortunately we have no investigations of the biological conditions in the Barents Sea in the winter of 1902—03, but we have pointed out that in the preceding spring (1902) the temperature of the sea along the meridian of 33° 30′ E. Long. was abnormally low (cf. Fig. 59 Curve III), and the distribution of ice was abnormally extensive (Fig. 59 Curve IV). We may therefore conclude that the water of the Barents Sea has been very cold still farther east during the following summer and winter, and owing to the great distribution of ice in the spring and summer (May & June) of 1902, there has been a great reduction of the plankton life in the Barents Sea, as hardly any phyto-plankton is formed under the ice. There has consequently been very little food for the seals and white whales during the following winter, and this may have been the cause of their emigration. At the same time there was probably a comparatively small stock of fish in the sea, as the spawning had been comparatively unfavourable in the years of 1894—1896 (cf. Fig. 74) (1). With these circumstances coincided the exceptionally unfavourable biological conditions in the Lofoten sea in the season preceding the Lofoten fisheries of 1903, when the Atlantic water had a maximum of temperature and the fish arrived unusually late and in an abnormally poor condition. As some part of the quantity of Lofoten cod probably comes from the north, it is also possible that the unfavourable conditions in the northern sea-area near the Barents Sea (owing to the low temperature and the great distribution of ice in the preceding year) has had some influence, and that it consequently is the coincidence of unfavourable conditions, both in the Atlantic Current and farther north, that was the cause of the abnormal condition of the cod in 1903.

Summary. Our investigations of the annual (or secular) variations of the Norwegian Atlantic Current have led us to the following conclusions:

1) Observations of the mean temperature of the Atlantic water, in the southern Norwegian Sea at the surface as well as in the deeper

(1) The spawning may, however, have been better in 1895 than in 1894 and 1896, and the quantity of spawning cod seems to have been unusually great at that time (cf. Fig. 74, Curve III).

layers, afford a method of predicting, several months, or more, in advance: the anomaly of the air-temperature in Norway, the prospects of the Lofoten fisheries (whether they will come early or late), the growth of the fir wood, the agricultural prospects, and probably also the growth and spawning of the food-fishes, which again determine the fisheries several years later.

2) Some prognoses of this kind may be based on meteorological observations, but a much greater number of observations, distributed over a large area, would be required, and the mean of even a huge observation-material of this kind, would give no more trustworthy prognosis.

3) The thermal conditions of the Atlantic water are partly of primary, partly of secondary nature, as compared with the thermal conditions of the air in Norway. The conditions *under the surface* are chiefly primary; they determine the anomaly of the air-temperature of Norway, especially in the winter and spring, because different quantities of heat are given off to the atmosphere by the vertical circulation of the water-strata during the cold season. The thermal conditions of the air (and its moisture, amount of clouds etc.) influence the surface-temperature of the sea, which so far is secondary. In this manner we find that a *low temperature*, or rather a comparatively *small quantity of heat*, contained in the layers of Atlantic water *below* the surface, should as a rule be followed by a *low* temperature *at* the surface the following year, and *vice versa*. This agrees with our observations of the surface-temperatures of the four years 1901—1904; but 1905 forms an exeption in this as in other respects (see above).

4. The *mean temperatures* and the *volume* (sectional area) of the Atlantic water *below* the surface, in a section across the southern Norwegian Sea (Sognefjord section) in May, can be used for the prognosis of the character of the air-temperature of Norway in the following winter, the time of the Lofoten fishery (whether early or late) the following winter, probably also the character of the spawning and the relative quantity of cod-liver.

The *surface-temperature* of the Atlantic water along the same section in May, can be used for a prognosis of the growth of the fir wood during the summer a year later, and the quantities of the products of agriculture in the following autumn, in a similar manner as the air-temperature in the spring may be used for the same purpose.

4. The Seasonal Variations.

In 1903 four seasonal cruises were made, in February, May & June, August, and November, the observations being chiefly made in the southern part of the Norwegian Sea (the Sognefjord section). In no other year we have cruises in all four seasons and we shall therefore base our discussion of the seasonal variations upon the observations from 1903.

Figs. 75—78 have been reproduced from our Plates, and demonstrate the most characteristic variations in the Sognefjord section during that year. The variations are, in some respects, rather considerable. The course of the 35·0-isohaline, near the Norwegian coast, representing the boundary between the Atlantic water and the coast-water, differs in the different seasons. The horizontal distance, at the surface, from land to this isohaline (on the inside of the Atlantic water) had a maximum in August and a minimum in November. We shall return to this point in the next chapter and will here only point out that the coast-water shows a marked tendency to spread seawards at the surface in the spring and summer, and to retire towards land in the autumn. The 35·0-isohaline at the surface will accordingly show lateral oscillations, as is demonstrated by our Figures 75—78. This phaenomenon is due to the relation between the velocities of the currents and the density of the surface-water in different seasons. The coast-water will grow lighter during spring and summer on account of the increase in temperature and the increase of the fresh-water supply; and it will therefore have a greater tendency to spread seawards, as the density of the Atlantic water does not decrease in the same proportion. The waters will have a distribution corresponding to the velocities of the currents. The rotation of the Earth deflects the water towards the right of the current, with a force which is proportional to the current-velocity, and the water-masses will adjust themselves in such a manner that this force will be counter-

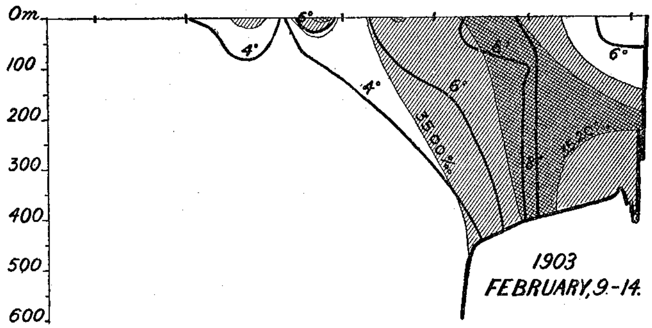

Fig. 75

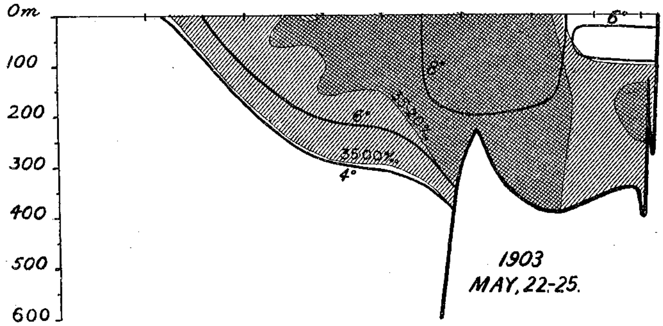

Fig. 76.

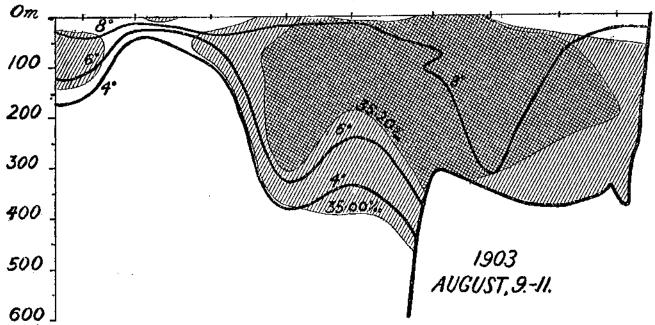

Fig. 77.

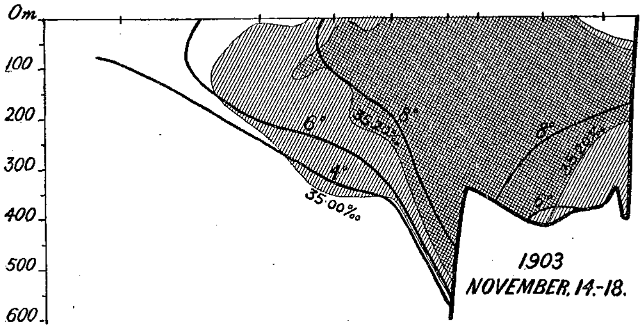

Fig. 78.

Figs. 75—78. Sections seawards from Feje (Sognefjord), February—November, 1903.

balanced by a force in the opposite direction, due to the distribution of density. Lateral equilibrium is attained when these two forces are equal. We therefore find water with low density to the right of the current, and with high density to the left. Supposing the velocity to be fairly constant, the force of density will become greater than that of rotation when the waters near the coast are heated, and the coast-water must accordingly move seawards. When the coast-water in autumn and winter is cooled, the force of density will decrease and become smaller than the force of rotation, which will therefore drive the water nearer to the coast. In this manner great seasonal variations must be caused in the lateral distribution of the coast-water and the Atlantic water, as has been pointed out by Nansen [1902, p. 398]. Our later observations have perfectly verified the correctness of his view on this point. A similar lateral oscillation of the coast-water would also be effected by regular variations of the Atlantic Current, if its velocity had a maximum in autumn and a minimum in spring or summer. We do not yet know with sufficient certainty whether such variations of this current take place or not; but the calculations from the Færoe-Shetland Channel, referred to above, seem to indicate that the variations go rather in the opposite direction.

The Plates, and also Figures 75—78, show that the shapes of the isotherms vary greatly during the year. In February the isotherms, as well as the isohalines and isopyknals, have almost a vertical direction, while in August they run much more horizontally. This is evidently due to the thermal effect from above. When the sea-surface is cooled in winter, important vertical convection currents are produced. The water of the upper layers will then get mixed and become homogeneous, and the equilines will acquire very steep inclinations. This is clearly demonstrated by the sections of January—March, 1901 (Pl. XV), and February, 1903 (Pl. XX). The observations at Stat. 2 A (Pl. XX, Fig. 1) show, for instance, that the temperature, salinity, and density were perfectly uniform from 100 to 350 metres below the surface (within the errors of observation), the surface of this homogeneous water being covered by water with somewhat lower temperature and salinity, which had probably been driven westwards by the winds. The vertical convection currents may in this manner descend to a great depth, often to

200 metres, sometimes much deeper, constantly bringing warm water to the surface from below. We may thus easily account for the great effect of the warm waters upon the temperature of the air.(1)

We have calculated the mean temperature of the Atlantic water in the Sognefjord section for the different seasons of 1903 in the manner employed in the case of the various years dealt with above. When comparing the values thus obtained (and the diagrams), however, we must bear in mind that we have to deal with different masses of water; for the water found in the Sognefjord section in May has been far to the south of the section in February, and will be far to the north of it in August. As the water changes its position in this way, we cannot study the variations in one particular volume of water by sections along one line, but would have to follow the moving water northwards. The folloving mean temperatures calculated by us in the Sognefjord sections do not, therefore, show the conditions of the same water, but the conditions in the same locality.

Mean Temperature of the Atlantic Water, in the Sognefjord Section in 1903.

	February.	May.	August.	November.	Average.
t° C. Below the Sea-Surface (depths disregarded).					
35·00— ·19 ‰	7·37	6·12	6·52	7·01	6·76
Above 35·20 ‰	8·05	7·63	8·01	8·70	8·10
Above 35·00 ‰	7.86	7·23	7·66	8·13	7·72
t° C. At Certain Depths; Salinities above 35·00 ‰.					
At the Surface	7·59	7·41	10·83	8·54	8·59
50 metres	—	7·48	7·75	8·64	—
200 »	—	6·69	7·55	8·00	—

(1) It is, however, clear that, wherever the sea is covered by a thick or thin top-layer of lighter water, with so low salinities that the surface-water cannot by cooling become heavier than the underlying water, no such great vertical convection currents will arise. The Atlantic water will then be protected against cooling by the overlying lighter water, but at the same time the atmosphere in that region will not be heated by the great volume of Atlantic water underlying the surface-layer. It will thus be understood that annual variations in the quantity and distribution of the coast-water may have an influence upon the quantity of heat given off to the atmosphere from the Atlantic water.

The upper part of the table shows the variations in the mean temperature of the whole volume of the Atlantic water below the surface in the Sognefjord section (west of Stat. 2 A or 3). The average value for all four seasons is found to be 7·72 ° C. The differences from this average in the different seasons are strikingly small. The lowest temperature was found in May (7·23° C.), and the highest in November (8·13° C.), the difference between these two values being even less than 1 ° C., and not greater than the annual variations in the temperature of May (*e. g.* 6·20 ° C. in 1901, and 7·24 ° C. in 1902). The variations at a certain depth seem to be a little greater (between May and November, at 50 metres 1·2 ° C., and at 200 metres 1·3 ° C.). The amplitude during one year, of the mean temperature of the Atlantic current below the surface seems therefore to be only about 1 ° C.

The variations at the surface are considerably greater. The lowest mean temperature was found to be in May, 7·41 ° C., and the highest in August, 10·83 ° C. — a range of 3·4 ° C. It is rather remarkable that the mean temperature of the Atlantic water at the sea-surface was a little higher in February than in May; the absolute minimum would probably have been found in April (about 7 ° C.?) and the maximum perhaps in September (about 11 ° C.). We may in this connection point out that our calculations refer not only to the Atlantic water in the main body of the current (near the continental slope) but also to those waters, with salinities above 35·00 ‰, which occur farther west, and which probably form the western parts of vortex-movements such as have been mentioned above. The mean temperature of the main body of the current, near the continental slope, would have been higher than calculated above. For the whole mass of Atlantic water at the surface in the Sognefjord section we find a yearly average range of about 4 ° C., with a minimum of about 7 ° C. and a maximum of about 11 ° C.

The Atlantic water below the sea-surface has a higher mean temperature in February than in May, or even than in August. The calculations for February have been based, however, upon a rather incomplete observation-material, and may therefore be too inaccurate to be compared with the values of the other seasons. Such as they are, our observations indicate that the minimum of mean temperature of the Atlantic water, below the surface, occurs in May or later (June), the time of minimum temperature thus being retarded at intermediate depths as compared with the conditions at the surface. The maximum temperature in each depth, as well as on an average in the whole volume of water, occurs in November.

The table above also elucidates very clearly the variations of temperature that are due to the heating and cooling from above. In February the mean temperature at the surface is about 0·3° C. lower than the average temperature of the whole mass of water; the surface at this time of the year is cooled considerably as compared with all Atlantic layers found deeper. We should, in all probability, have found almost the very same mean temperature at 50 metres as at the surface, if the observations had been sufficient for a calculation; and on account of the vertical convection currents we should have expected to find the same temperature even at 100, or 200 metres' depth. In May the mean temperature at the surface was almost exactly the same as at 50 metres, and 0·8° C. higher than at 200 metres; but in August the difference is very great, the mean temperature at the surface being 3·1° C. higher than at 50 metres, a fact which gives a clear idea of the heating from above in summer. In November the cooling at the surface had commenced (cf. Stats. 3 B, 4 B, and 62, Pl. XXIII, Fig. 1); the average temperature was 0·1° C. lower at the surface than at 50 metres.

In February 1903 a section was made from Jan Mayen to Vesteraalen, to the north of the Lofoten section of May—June. As the observations were not taken sufficiently deep in the sea, we cannot calculate the mean temperature of the whole volume of Atlantic water there. The mean temperature at the surface was 4·0° C.; and thus the difference between the temperatures of the southern and northern sections was in February as much as 3·6° C., indicating a rapid rate of cooling in the northern part of the Southern Norwegian Sea. The difference at the surface between the Sognefjord section and the Lofoten section in May—June was very small, only 0·1° C.; but the observations in the latter section were made a fortnight later than in the former, during a season when the heating of the surface had commenced, while the reverse was the case in February.

Variations of salinity similar to those of temperature are very difficult to trace with sufficient certainty. The observations (and the sections in the Plates) indicate a maximinum of salinity in August and a minimum in February. The differences between May, August, and November are however very small, and the February observations are too few to allow of certain conclusions being drawn with regard to this point. The mixing process performed by the vertical convection currents will in most cases, however, cause a decrease of the highest salinities; but we know nothing about the mean salinity of the Atlantic water in this month. We may mention in this connection that MARTIN KNUDSEN [1905] has found from a statistical treatment of a great number of surface observations from the northernmost part of the Atlantic Ocean, that the salinity had a maximum value at the end of April and beginning of May (on an average 0·03 ‰ higher than the normal) and a minimum in October (0·04 ‰ lower). The variations were thus very small indeed.

VIII. The Norwegian Coast Water.

1. Salinity and Temperature.

In accordance with the ordinary terminology we will as a rule regard waters along the coast, with salinity below 35·0 ‰, as coast-water. The boundary between the Atlantic water and the coast-water at the surface is generally very sharply defined in the Norwegian Sea, the transition being very sudden from waters with salinity below 35 ‰ to those with salinity above 35 ‰. The surface areas covered by water with salinities between, say, 34·7 and 35·0 ‰, are, on the whole, quite small and narrow in the Norwegian Sea. But it is not in all cases easy to draw the boundary line in the charts, because small areas of coast-water and Atlantic water may be met with alternately, as for instance in November, 1903 (Pl. XI, and XXIII, Fig. 3). Such irregularities may be caused by vortex-movements (see above, Chap. VI), or by temporary displacements of the surface-layers, due to the wind. A heavy rainfall within the area of the Atlantic water may also occasionally cause a decrease of the salinity. A rainfall of 50 millimetres (2 inches) will diminish the average salinity of the upper 5 metres *e. g.* from 35·2 ‰ to 34·8 ‰. In this manner the Atlantic water may get the same character as the coast-water without having any connection with the coast at all. Such cases are not easily distinguished in our observations, because the heavy rainfalls generally are local and the ship was as a rule continually moving.

The following examples may be given in order to elucidate this point: It rained in the afternoon, on June 5th, 1904, when the Stations 25 and 26 were taken (cf. Pl. XXIV A, Fig. 3).

The following surface-observations were made:

	5, VI, 1904.							6, VI, 1904.
At	5 p. m.	6	7	8	9	10	11	1 a. m.
S ‰	34·73	34·65	34·62	34·32	34·50	34·68	34·81	34·86
t ° C.	8·08	8·08	7·95	8·08	8·17	8·02	7·97	8·07

The first of these observations (5 p. m.) were made at Stat. 25, and the last (on the 6th, 1 a. m.) at Stat. 26. The temperature of the air was 8° or just the same as the surface temperature. The wind was blowing from WSW, at about 7 metres per second. The following observations were taken at the stations:

	Stat. 25.		Stat. 26.	
	Temp.	Salinity.	Temp.	Salinity.
Surface . . .	8·08	34·73	8·07	34·86
10 metres . .	7·91	·74	·02	35·03
20 — . .	6·99	·87	7·98	·06
30 — . .	7·24	·98	·38	·06

The water at Stat. 25 with low salinity was probably real coast-water. But the low surface-salinity at Stat. 26 might as well be due to the rain, which the course of the isohalines may indicate. It is then impossible to decide how far the real coast-water, from the east, extended westwards at the surface.

While the transition from waters with salinity below 35 ‰ to those with salinity above 35 ‰ generally is very sudden at the surface, this is not the case vertically, on the boundary between coast-water and Atlantic water at intermediate depths, where the variations of salinity are relatively slight in most cases. The variations are much greater nearer to the surface, at salinities about 34·5 or 34·0 ‰.

The surface-salinity close to the west coast of Norway, outside the "skjærgaard", is generally above 31 ‰, increasing more or less rapidly towards the Atlantic Current. This coast-water is thus composed of less than $\frac{1}{8}$ of fresh water and more than $\frac{7}{8}$ of Atlantic water. The surface-salinity varies annually as well as seasonally, the seasonal variations being the greater (see later). It increases northwards along the coast, as will be seen from the following table which contains some observations made by the Swedish, German, Norwegian, and Russian oceanographers in May and the beginning of June, 1904; the stations referred to in this table, have nearly equal distances from the coast, with the exception of Stat. N 40 which was farther from the coast than the others.

Stations near the Coast, from Skagerack to the Murman Coast (May—June, 1904).

Station		**S Skag. 9**	**D Nord-see 8**	**N 1**	**N 40**	**N 24**	**R 2**
Date		May 12.	May 4.	May 21.	June 10.	June 3.	May 9.
Latitude N		58° 21′	58° 20′	61° 0′	62° 26′	67° 12′	70° 0′
Longitude E		8° 56′	5° 43′	4° 10′	3° 34′	10° 8′	33° 30′
Sounding (metres)		253	360	ca. 350	188	227	150
Surface.	t°	6·8	5·79	7·25	8·97	6·39	2·78
	S ‰	28·44	32·20	32·28	32·95	33·55	34·33
	σ_t	22·32	25·27	25·27	25·545	26·38	27·39
20 metres	t°	5·93		6·86	8·94	5·61	2·75
	S ‰	31·00	33·83	32·75	32·84	33·71	34·42
	σ_t	24·44		25·70	25·455	26·61	27·46
50 metres	t°	4·72		5·71	7·07	5·40	2·70
	S ‰	34·38	34·605	34·42	34·73	34·19	34·43
	σ_t	27·24		27·15	27·22	27·005	27·48
100 metres	t°	4·94	5·55	6·61	7·10	6·51	2·63
	S ‰	34·83	34·85	34·99	35·12	35·05	34 51
	σ_t	27·57	27·50	27·485	27·515	27·54	27·56
150 metres	t°	5·04		7·03		6·53	
	S ‰	34·87		35·16		35·10	
	σ_t	27·59		27·56		27·585	
200 metres	t°	5·17		7·01		6·41	
	S ‰	34·92		35·21		35·14	
	σ_t	27·61		27·61		27·635	

These stations have not been taken at the same time but may probably be used for a comparison of the salinities found at different parts of the coast in general. The surface-salinity increases from the Skagerack (28·3 ‰ in May, 1904) along the Norwegian coast northwards to the Barents Sea (34·3 ‰ off Alexandrovsk). The salinity is also everywhere increasing from the sea-surface downwards (except in one case, Stat. N 40, where the salinity was a little less at 20 metres than at the surface). At greater depths, for instance at 100 metres below the sea-surface, the salinity is much the same along the whole of the Norwegian coast; the maximum value, 35·12 ‰, found at Stat. N 40, is partly due to the situation farther seawards of this station, but partly also to the fact that the coast north of Stad is approached nearer by the Atlantic Current than the other parts of the coast. A distinct minimum of salinity at 100 metres was found in the Barents Sea, at Stat. R 2, where the waters were almost homohaline from surface to bottom. The difference of salinity vertically, between the surface and 100 metres, was 6—7 ‰ in the Skagerack, 2—3 ‰ along the southern and western coast of Norway, 1—2 ‰ off northern Norway, and only 0·2 ‰ at the Russian station off the Murman Coast.

The coast-water is on the whole moving along the coast of Norway, as a continuation of the Baltic Current, from the Skagerack to the Barents Sea. The distribution of salinity demonstrated by the table above, proves that great mixing processes take place as this coast-water proceeds northwards. Along the Murman Coast the salinity is always very uniform in May, between 34 and 35 ‰. This intermixing is partly caused by the movements of the horizontal currents (vortex-movements, etc.), and partly by the vertical convection currents in winter. It is worthy of note that the average salinity is, on the whole, increasing along the route of the coast-water, while the average salinity of the Atlantic water is decreasing northwards, so that the salinities are much more uniform in a section through the Barents Sea, or through the Norwegian Sea seawards from northern Norway, than they are in the southern part of this sea. The coast water is thus in part intermixed with the waters in the upper layers of the Atlantic Current, while in return the Atlantic water from below is intermixed with the upper water-layers near the coast.

As the salinity of the upper layers increases northwards and that of the deeper layers decreases, so as to produce a vertical distribution of salinity which is much more uniform in the north than in the south, the conditions as regards the formation of vertical convection currents in winter, will be very different: they will not be formed to such an extent along the southern coast of Norway, as along the northern coast, off Finmark, where they cause a complete homohalinity in February to April, in the upper layers down to between 50 and 200 metres.

The table above demonstrates the distribution of temperature in May and June, 1904. The differences of surface-temperature are due to the differences of time as well as to the different geographical positions of the stations. The surface-temperature of the coast-water varies much according to the meteorological conditions, and may increase or decrease several degrees in a few weeks; the differences between the Stations S Skag. 9, D Nordsee 8, and N 1 would have been very much reduced if the various observations had been taken at the same time. But in the intermediate strata, *e. g.* at 20 metres, the differences of temperature between the stations along the Norwegian coast are still greater than at the surface, and this cannot be accounted for merely by the difference of time. It is chiefly due to the origin of the waters and the encounterance with other waters. The waters of the Baltic Current are cooled to a low temperature in winter, and the intermediate temperature found in the Skagerack in May is very much lower than farther to the west and north, where the cooling in winter is much less, owing to the effect of the Atlantic water in the Norwegian Sea. The distribution of temperature has very great variations that will be discussed later. As a general feature we may here only indicate that the temperature of the coast-water in Skagerack has a greater resemblance to the air-temperature on the Continent, than farther to the west and in the Norwegian Sea, where the "climate" of the coast-water is much more like the "Oceanic Climate", with comparatively small variations.

2. The Movements of the Norwegian Coast Water.

Some direct measurements of the movements of the waters along the Norwegian coast have been made during the summer, in July and August, of 1906 and 1908; but as there are no observations of velocity and direction of the coastal current from other seasons or other years (except in Skagerack), we cannot draw as general conclusions from these observations as would have been desirable.

The coastal current of Norway originates from the Baltic Current passing through Kattegat into the *Skagerack.* The current follows the Swedish side of Kattegat; after a bend in the northern part of the Skagerack it runs close to the Norwegian Coast, generally with great velocities. A velocity near the surface of about 1 metre per second has been repeatedly measured by Swedish and Norwegian oceanographers.

On July 27th, 1906, a series of observations off Risör, where the depth to the bottom was 180 metres, gave an average velocity in the upper 20 metres below sea-surface of about 70 cm. per sec.; just a little below the surface the velocity sometimes reached considerably higher values. A maximum of mean velocity was observed at 10 metres. The Atlantic water was probably at depths below 75 metres; all waters nearer to the surface moved almost in the same direction, parallel to the coast, with velocities that were decreasing from 10 metres downwards. The variations in direction were comparatively small. In the Atlantic water at 100 metres below the surface, the Current was moving in the same direction as the overlying water of the Baltic Current, at an average rate of a little less than 10 cm. per sec. (5 naut. miles in 24 hours). At 170 metres, in the deepest layers of the Atlantic water at the station referred to here, no ordinary current was observed, but in these layers the tidal currents were predominating; they were quite noticeable, even if the velocities were very small, less than 5 cm. per sec. [HELLAND-HANSEN, 1907 a]. Similar measurements from other parts of the Skagerack, some days afterwards, proved also that the tidal currents were indistinguishable in the upper layers, but could be easily observed near the bottom. Prof. PETTERSSON has afterwards shown, from observations in 1907, that the tidal wave proceeds farther eastwards through Kattegat and the Belts, in the deeper layers and not at the surface [1908].

Although the number of direct measurements of the Baltic Current in the Skagerack is very small, they seem to prove that the current as a rule runs at a great rate near the surface, with insignificant variations in direction. The measurements referred to above showed, however, rather great variations in velocity; but more observations would be required in order to settle the question whether these variations are periodic, and we cannot therefore with full certainty decide, whether the Baltic Surface-Current in Skagerack is subject to any tidal influence or not.

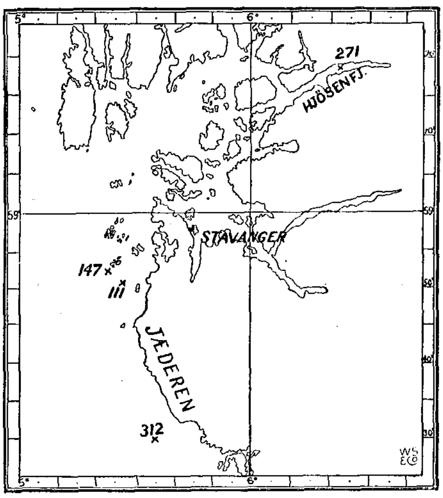

Fig. 79. Chart showing the Stations of Current-Measurements off Jæderen and in the Hjösenfjord.

Three stations of current-measurements have been taken in the coastal current off *Jæderen*, by the *Michael Sars*. The chart, Fig. 79, shows the position of these stations as well as that of an important station (271) in the Hjösenfjord, which will be referred to later. Stat. 312

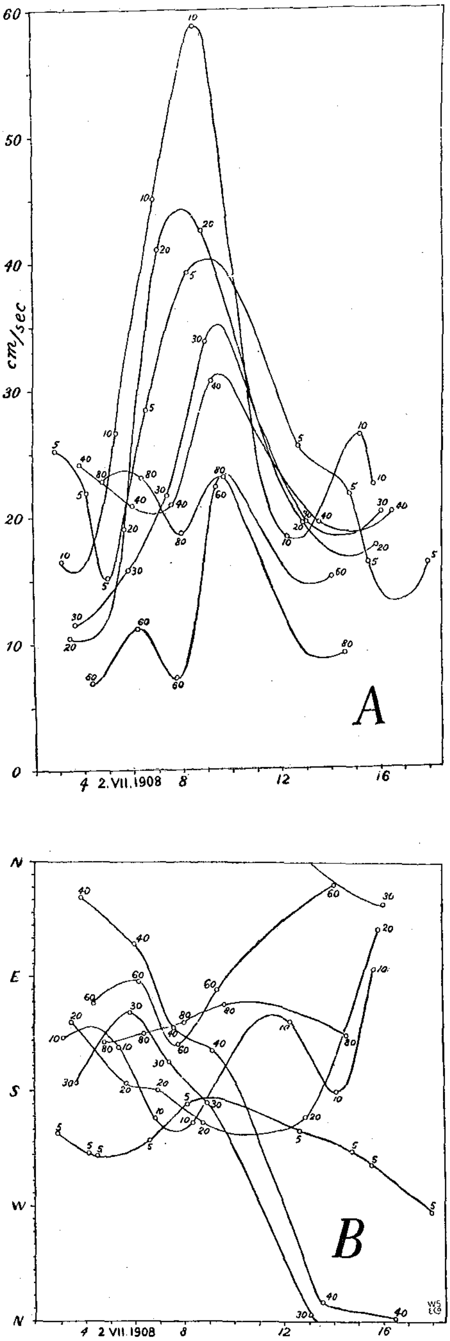

Fig. 80. Current Measurements at Stat. 111. A, Curves of Velocity for different depths. B, Curves of Direction.

(sounding 230 metres) was taken on July 23rd, 1906. The observations then made revealed great variations in velocity as well as in direction. The curves of direction demonstrate the typical course of a tidal current, but the velocities were, at all depths down to 100 metres (where Atlantic water was observed some time afterwards), always greatest with a north-going current and least with a south-going. At 200 metres below sea-surface, in the Atlantic water, the reverse seemed to be the case. These observations seem to show that in the upper layers, down to about 100 metres, there was a fairly strong average current from south to north, and that in the bottom-layers a slow current was going in an opposite direction [HELLAND-HANSEN, 1907a].

Stat. 111 (58° 50′7 N. Lat., 5° 26′8 E. Long.; sounding 113 metres) was taken on July 2nd, 1908, by Captain THOR IVERSEN, of the *Michael Sars*. A fresh wind was blowing so that it was impossible to work from a small boat tightly strained between two grapnels, in which manner the Norwegian current measurements were generally taken. The measurements had to be made from the steamship at anchor; by the wind and the strong current it was kept without appreciable movement during the first hours of observation (till about 10 a. m.). The observations made afterwards are not perfectly reliable although the results seem to indicate that the swaying of the ship has been of but slight importance. The observations have been introduced in Fig. 80. A represents the curves of velocity at different depths, and B the curves of direction. The variations of the current were very great. At 10 metres, for instance, the velocity was 16·4 cm. per sec. at 3.04 a. m., and 58·6 cm. per sec. at 8.19 a. m. At 20 metres the velocity was 19 cm. per sec. at 5.38 a. m., and 43 cm. per sec. $1^1/_4$ hour afterwards, at 6.56 a. m. Even at a depth of 60 metres great variations were observed. The variations are so great and rapid, that it is almost impossible to draw the curves in a trustworthy manner; they cannot be but hypothetical to a great extent. Great changes of direction were also found, except at 5 and at 80 metres below the surface. At 5 metres the water was moving from south-west to north-east with comparatively small variations in direction; in the afternoon the current at this depth seemed, however, to have turned towards the east. At 80 metres the current had a direction from south-east to north-west, forming approximately an angle of 90° to the direction of the current at 5 metres below the surface. But the curves of direction for intermediate depths show great variations; provided that the course of the lines are fairly correct, they indicate tidal currents as well as the ordinary current. The curves of direction seem to show that there were several tidal waves passing the place where the measurements were made, probably one or more reflected waves besides the primary one. However it be, it is quite obvious that the current was subject to very many and great variations off Jæderen. But one thing seems certain: the velocity reached a maximum value when the current was moving from the south (between south-west and south-east) towards the north; this was the case between 7 and 9 a. m., at all depths down to 40 metres. At 60 metres the maximum velocity was found a little later, when the current at this depth had a direction from the east. It is also noteworthy that the current sometimes had a direction straight seawards from land, and even then with comparatively great velocities. This was, for instance, the case at about 4 p. m. (if the observations be correct) between 10 and 30 metres, where the velocity amounted to something about 20 cm. per sec.; but not at 5 metres where the current was always coming from somewhere between south and west.

Station 147 (58° 52'3 N. Lat., 5° 23'2 E. Long., sounding 117 metres) was taken on July 10th and 11th, 1908. The observations were made from a small boat that was kept perfectly still between two grapnels, fore and aft, the lines of which were tightened up as hard as possible, and the boat was also pressed by the strong current at the surface. The measurements are highly interesting but difficult to expound. We find similar variations at this station as at Stat. 111, especially in the velocity. The velocity was in by far the most cases decreasing from surface to bottom; the velocity was remarkably great in the uppermost strata, at 2 metres always above 1 meter per second, during the whole time of observation. Even at 40 metres velocities upwards of 50 cm. per sec. were observed. Near the bottom, at 100 metres, the greatest velocity observed was about 19 cm. per sec. The variations differed in different layers, as will be seen from the following table giving the maximum and minimum velocities, and the average velocity (in cm. per sec.) observed at different depths:

Metres	2	5	10	20	30	40	60	80	100
Maximum Velocity	122·4	111·9	93·2	61·2	68·7	56·9	34·5	18.3	18·7
Minimum Velocity	103·7	81·7	47·9	28·8	20·6	5·0	6·1	1·8	2.1
Difference	18·7	30·2	45·3	32·4	40·1	51·9	28·4	16·5	16·6
Average Velocity(1)	111·9	95·8	70·5	48·6	41·8	25·7	17·8	13·2	8·9

(1) The average velocities given in this table are the simple means of the observations (between 9 and 15 observations at each depth), without considering the direction.

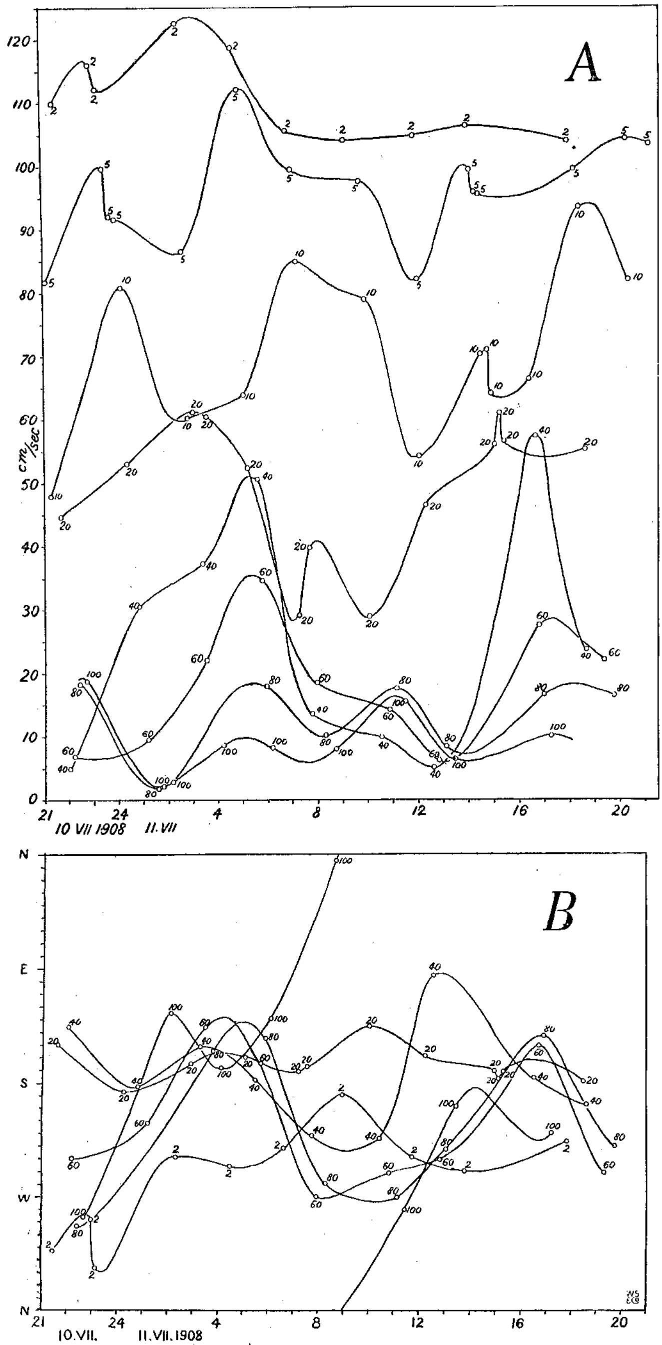

Fig. 81. Current Measurements at Stat. 147, July 10th and 11th, 1908. A, Curves of Velocity for different Depths; B, Curves of Direction.

The variations in the velocity were small at 2 metres, compared with the average velocity of the current. The variations were particularly great at 10 and 40 metres.

The observations have been plotted out in Fig. 81; A representing the curves of velocity at different depths, and B representing the directions. The curves show considerable variations wherever the observations have been taken at short intervals. We may certainly conclude that the curves are only rough approximations to those that would have been drawn by means of more determinations, many variations having obviously escaped observation. There are some striking features that seem to be correct, *e. g.* the chief variations in velocity in the upper water-strata, between 2 and 10 metres. The curves of Fig. 81, A, especially for 5 and 10 metres, show very nearly the same variations, but the maximum and minimum values of velocity

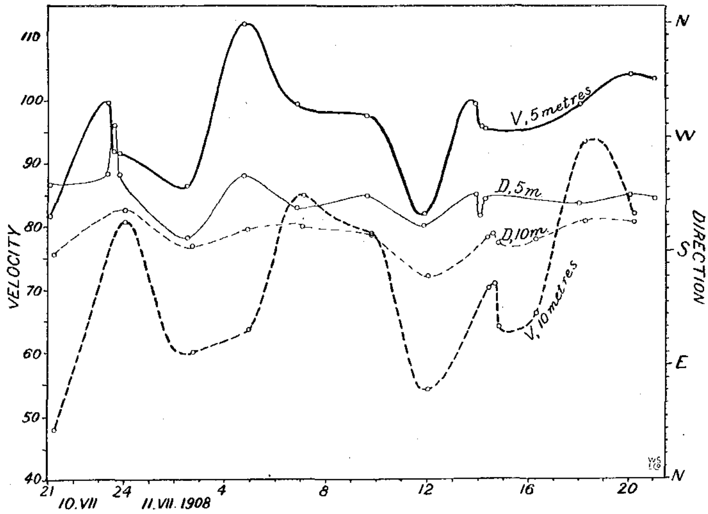

Fig. 82. Curves of Velocity (V) and Direction (D) of Current at Stat. 147, 5 and 10 metres.

occur later at 10 metres than at 5 metres. Fig. 82 shows the curves of velocity and direction for 5 and 10 metres. It will be seen that there is a certain agreement between velocity and direction at these depths; the greatest velocities correspond to a direction from between south and west (*i. e.* from the open sea) while the current, almost in all cases, was slower at more easterly directions (*i. e.* from the land-side). Even small variations in direction may in this respect correspond to great variations in velocity.

Many of the curves in Fig. 81, A and B, seem to show a certain regularity, with periods of 6 or 12 hours, indicating the tidal influence. This is especially the case with the curves for 60, 80 and 100 metres. The curve of velocity at 100 metres represents a regular tidal current, iwth a period of about 6 hours; the curve of direction for the same depth has the oblique course characteristic of the variations of a tidal current, but with a remarkable bend at directions from the south (SW to SE). It will easily be seen that the current had considerably greater velocities when coming from between north and west than when running from the south. The observations show therefore that the ordinary current at 100 metres was going southwards, just as it was found by the observations in 1906 (in the deeper layers at Stat. 312). At 80 metres similar periodical movements were found, but it is remarkable that the curve of velocity shows periods of 6 hours, while the curve of direction has a period of 12 hours. Both curves for 60 metres show periods of 12 hours, and none of 6; the current at this depth had a minimum when coming from the west, and a maximum when coming from the south or south-east. As the primary tidal wave at Jæderen is coming from about north-west it seems as if the current at 60 metres is increasing at ebb-tide, but not at flood-tide; it would, then, be intermittant and only reach considerable velocities during the reflux of the waters from this part of the coast. Professor GRUND [1909] has found similar conditions in the deeper strata of the Byfjord near Bergen in his discussion of current-measurements made by the Bergen Biological Station.

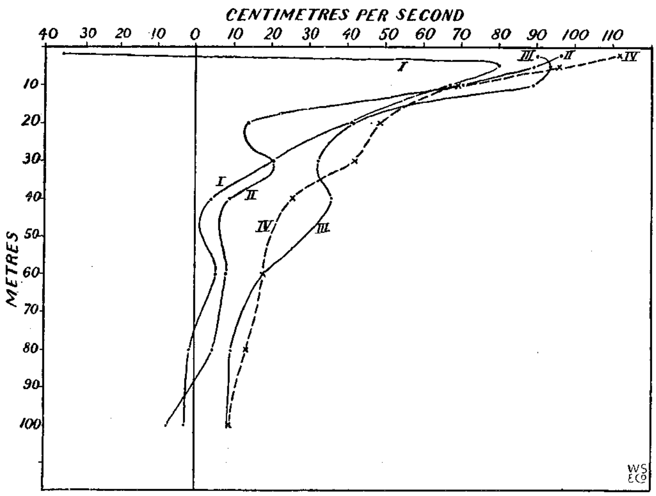

Fig. 83. Current-Diagram, Stat. 147. The Curves I—III give the components in the direction parallel to the Coast, from S 20° W; I at 10—11 p. m., July 10th, 1908; II at 10—11 a. m., July 11th; III at about 5 p. m., July 11th.— The curve 4 gives the mean velocities, without considering the direction.

Fig. 83 demonstrates the currents between the surface and the bottom, at various times during the observations. The Curves I to III represent the components of the currents parallel to the coast-line, from S 20° W to N 20° E; I at 10—11 p. m., on July 10th, 1908; II at 10—11 a. m., July 11th; and III at about 5 p. m., on July 11th. The broken lined curve IV represents the mean velocities at different depths, without considering the direction. The three first-named curves show the transportation of water along the coast, and it will be seen, that this transportation may vary very much. At 10—11 p. m., on July 10th (Curve I), the water near the surface, at 2 metres, did not at all run northwards along the coast, the direction being approximately towards S 50° E; but the actual velocity was much the same as when the current was running northwards. The salinity at the surface was at the hours represented by the three curves 29·2, 29·3, and 29·8 ‰ respectively, no definite relation between the salinity and the direction of current being observed. But at 10 metres, for instance, the salinity increased, when the direction turned more from the open sea. At 100 metres (near the bottom) the salinity seemed to be rather constant, about 34·9 ‰, during the 24 hours of observation.

On July 6th & 7th, 1906, a number of current-measurements were made in the coastal water above the "Skrei"-Bank off *Söndmöre*, at Stat. 299 (sounding 70 metres; see the map in Fig. 41). The observations proved the existence of a current which went seawards, from east to west, in the upper 20 metres (salinity below 33 ‰), while a current in the opposite direction, towards the coast, was found in the deeper strata, below 20 metres (salinity above 33 ‰), as is clearly demonstrated by Fig. 84 [HELLAND-HANSEN, 1907 a]. The average velocities were rather small; at 2 metres 6·2 cm. per sec., and at 50 metres 8·6 cm. per sec. The casual velocities were sometimes quite considerable, in several cases above 20 cm. per sec. The observations revealed the existence of currents caused by the primary tidal wave as well as by a reflected wave.

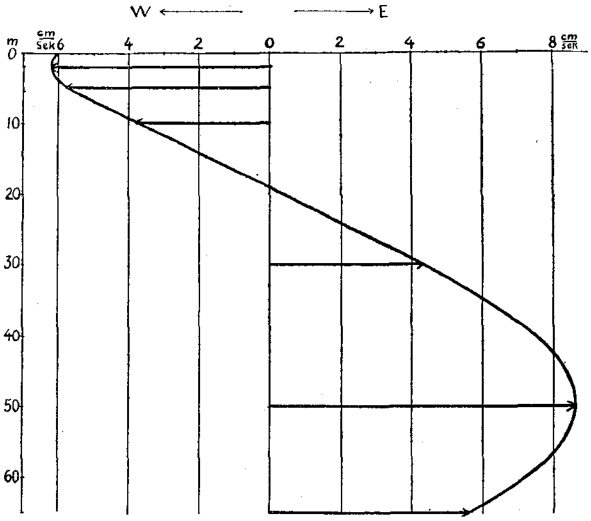

Fig. 84. Current Diagram, Stat. 299, July 6th & 7th, 1906 [HELLAND-HANSEN, 1907 a, Fig. 3].

We have mentioned above (p. 106, 152) that a series of measurements were made at the edge of the continental shelf (Stat. 307; Figs. 24—26, 40 and 41) in July, 1906. The station was situated near the western surface boundary of the coast-water. The currents were here moving along the continental slope, at all depths. The coast-water at the surface was thus moving towards the west above the "Skrei"-Bank, and towards the nort-east farther seawards, along the continental slope. The coast-water at the surface north of Stad seems, therefore, to move away from the land until it is deflected towards the north and north-east near the edge of the continental shelf, where it joins the coastal current, coming from the south, and the Atlantic current. The observations hitherto made indicate that the coastal current described above, chiefly follows the edge of the continental shelf, in the same way as the Polar Current runs along the corresponding edge east of Greenland. The Norwegian Coast Current (as well as the East Greenland Polar Current) is checked over the uneven continental shelf. In July, 1906, no average northward movement whatever was found at the surface, above the banks off Söndmöre. But there may be great local variations in these conditions, *e. g.* on account of vortex-movements (with vertical axes); it may be, for instance, that the configuration of the coast causes such a vortex-movement to the north of Stad. The experiences of the fishermen, seem, however, to indicate that the surface-currents above the shelf are, upon the whole, rather slow along the whole of the western and north-western coast of Norway, and they are generally much more rapid along the edge of the continental slope, where the current sometimes attains very great velocities (*e. g.* at Andenes, Vesteraalen). The main body of the coastal current runs thus just alongside and parallel to the Atlantic current.

All current-measurements referred to here have been made in the summer. We know nothing about the velocity of the current in other seasons. From the distribution of salinity and temperature we know that the coast-water has a component seawards in summer and towards land in winter. The surface-current observed at the above-mentioned Stat. 299 is in accordance herewith; in winter we would perhaps have observed a slow movement in the opposite direction (cf. later).

The coastal current receives constantly additions of river-water coming from the *fjords*. The currents in the fjords have, in later years, been studied by a great number of direct measurements, some of which will be mentioned here.

At Stat. 271 of the *Michael Sars*, measurements were made in Hjösenfjord for 24 hours, on August 13th and 14th, 1908 (see Fig. 79). The velocity and direction of the current are represented by the curves in Fig. 85; A at the surface; B at 2 metres; and C at 5 metres. The maximum velocity was observed at the surface, where the water without exception was flowing with a constant direction seawards from the inner end of the fjord. Great variations in velocity were observed, but we know nothing as regards the periodicity as it must have been of 24 hours at least. At 5 metres the water was flowing in the opposite direction (inwards), with much less velocity. The velocity was also varying at this depth; when the current was very slow the direction altered very much, as has generally been found by all such measurements in the fjords. The conditions at 2 metres are very interesting (Fig. 85, B). In the afternoon of Aug. 13, the current at 2 metres had the same direction (from the sea into the fjord) and a greater velocity than the current at 5 metres. About midnight the current at 2 metres was very slow, and the direction was from south to north across the fjord, forming an angle of nearly 90° to the currents at the surface and at 5 metres. In the forenoon, Aug. 14, the current at 2 metres had another maximum, but followed then the surface-current (seawards). We find, thus, that the boundary between the opposite currents at the surface and at 5 metres oscillated vertically; the boundary was nearer to the surface in the beginning of the observations, when the surface-current had a minimum of velocity, and deeper down in the following morning, when the surface-current had its greatest velocity. A great number of measurements proved that the currents were very slow in the deeper strata; in most cases the EKMAN current-meter gave no registration. From 20 metres and downwards (to 200 metres) no current was found with velocity as great as 2 cm. per sec.(1) Hjösenfjord is an example of the typical barrier-fjords which are very common in Norway; the deep basin of the fjord is separated from the sea by a high ridge or sill, and the deeper water-strata have consequently almost no movements.

Fig. 86 represents some current-diagrams from the Byfjord at Bergen, which are based upon observations made by the Biological Station, on August 5th, 1908. The curves demonstrate the currents between the surface and 200 metres, at different hours of the day; the current has been calculated for the direction along the axis of the fjord. The surface-layer was constantly moving southwards, corresponding to the direction outwards from the fjord-system. A little deeper, at about 2 metres, the currents varied rather much, in both directions; it was chiefly due to the tides. Still deeper, down to between 20 and 40 metres, the waters were moving in the same direction as at the surface, with a maximum somewhere about 10 metres. The strata from these depths down to almost 150 metres were moving in the opposite direction, with

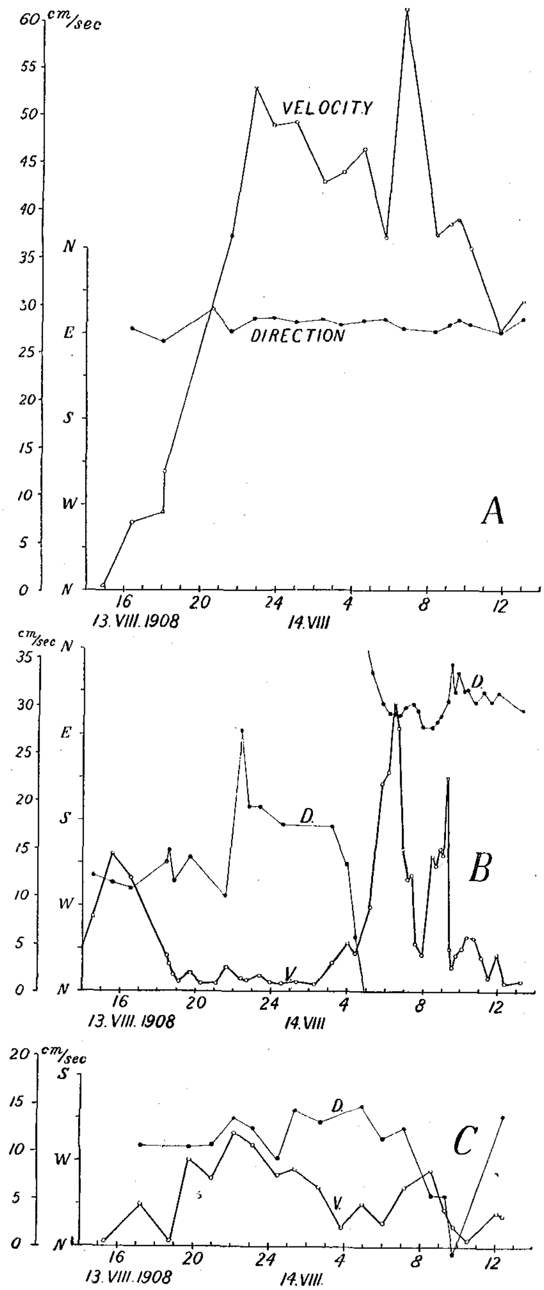

Fig. 85. Curves of Velocity (V) and Direction (D); A at the Surface; B at 2 Metres; and C 5 Metres. Hjösenfjord (Stat 271), August 13th & 14th, 1908.

(1) Similar conditions have been found by numerous observations in other fjords with sills.

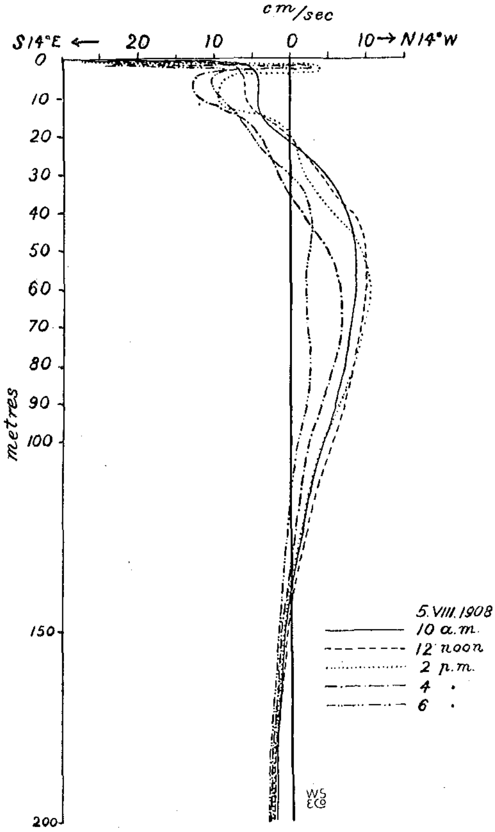

Fig. 86. Current-Diagram from the Byfjord near Bergen. August, 5th, 1908.

a maximum of velocity at 50—60 metres. The bottom-layers, from 150 metres downwards, were again moving out of the fjord. These observations show that the current system of such fjords as the Byfjord are rather complicated, having very different currents at different depths. They are moreover subject to considerable temporary variations; the series of observations referred to here may serve as an example of the conditions found in the fjords.

All current-measurements in the fjords have shown, that the surface-water is, on the whole, moving seawards (out of the fjords) in the summer. In the deeper strata, water is running into the fjords from the sea outside the coast and the islands, partly as a tidal flood-current, partly as a general drift and then obviously as a reaction-current, caused by the outflow of the surface water. Some of the water outside the coast will in this manner perform a kind of circulation; it will move into the fjord, get mixed with the water from the rivers and then be carried back again into the sea. These conditions explain many important biological problems, such as the distribution of different kinds of fish-eggs and larvae.

3. Annual and Seasonal Variations.

The variations of the coast-water are of different kinds and have many causes. The variations of salinity are, in the first place, due to differences in the rainfall and the melting of snow and ice on land. The Norwegian coast is passed by coast-water formed by admixture of river-water coming from very different parts of Northern and

Central Europe. All waters discharged from the entire rainfall district of the North Sea and the Baltic will, in fact, have their only outlet along the Norwegian Channel and northwards along the coast of Norway. The salinity, as well as the volume and velocity of the current will therefore depend upon the quantity of water discharged through the rivers of Germany, of Finland and great parts of Russia, of the whole of Sweden, and of the southern part of Norway. The volumes of water carried into the sea by all these rivers will depend upon the relation between rainfall and absorption of rain-water (the drainage) in the different districts, and on the intensity of melting (*i. e.* the insolation and the air-temperature). The values of these two factors, rainfall and melting of snow and ice, differ much in the different parts of the huge rainfall-district and at different times. The effect of these variations will be traced all along the Norwegian coast, but at different times, at first along the south-coast, and by and by farther northwards, depending upon the velocity of the motion. The phenomena are, therefore, very complicated. We have not had the opportunity of going into a detailed investigation as regards these questions and are therefore compelled to confine ourselves to a rather superficial study of the variations of the Norwegian coast water in relation to the meteorological conditions just mentioned. These conditions have by far the greatest effect upon the volume and velocity of the water along the Norwegian coast. The other causes of the variations, such as the varying conditions of the Atlantic water, are only of little importance compared with them.

The distribution of the coast-water will also depend upon the air-temperature and the insolation; these factors will cause seasonal variations in the horizontal extension of the coast-water which have been mentioned above (p. 227—229) and which will be discussed more fully later. The same factors will cause variations in the thermic conditions of the coast-water, seasonal as well as annual.

Annual Variations.

The annual variations of the coast-water may be studied by the observations in May and June, 1901 to 1904. Some observations from the southern part of the Norwegian Sea, of May, 1905,(1) will also be used for the following discussion.

The table shows the temperatures and salinities observed at Stat. 1, about 10 miles off Feje (at the entrance to the Sognefjord). The position of the station is very nearly the same every year; in 1902 it was, however, about 13 naut. miles farther to the south than in the other years. The date varies somewhat: the observations were taken a fortnight earlier in 1901 and 1902, and a week earlier in 1905, than in 1903 and 1904. There are unfortunately very few observations in the upper water-layers in the two first years.

Station 1 in May of different Years.

	1901,		**1902,**		**1903,**		**1904,**		**1905,**	
Date . . .	May, 5.		May, 6.		May, 22.		May, 21.		May, 15.	
Latitude N .	60° 58′		60° 48′		61° 1′		61° 0′		61° 0′	
Longitude E	3° 50′		4° 16′		4° 10′		4° 10′		4° 10′	
	t° C	S ‰	t° C	S ‰	t° C	S ‰	t° C	S ‰	t° C	S ‰
Surface	*6·2*	32·57	*6·0*	—	*7·3*	32·30	*7·25*	32·28	*7·21*	30·11
10 m.	—	—	—	—	*6·97*	·34	*6·93*	·75	*7·24*	31·52
20 »	—	—	—	—	*6·27*	·96	*6·86*	·75	*5·76*	32·36
25 »	—	—	*5·50*	32·50	—	—	—	—	—	—
30 »	—	—	—	—	*5·70*	33·46	*5·79*	33·89	*5·23*	33·24
40 »	—	—	—	—	*5·24*	34·18	—	—	—	—
50 »	*5·75*	34·43	*5·29*	33·57	—	—	*5·71*	34·42	*5·41*	34·23
75 »	—	—	*5·73*	34·32	*5·47*(2)	34·67(2)	*6·00*	·76	*5·89*	·83
100 »	*6·82*	34·93	*6·08*	·65	*6·37*	35·02	*6·61*	·99	*6·12*	·94
150 »	*7·07*	35·19	*6·58*	·96	*7·55*	·14	*7·03*	35·16	*6·31*	35·10
200 »	*6·92*	·16	*6·98*	35·18	*7·00*	·23	*7·01*	·21	*6·60*	·17
250 »	*6·80*	·16	—	—	—	—	*6·58*	·22	*6·31*	·24
300 »	—	—	*6·80*	35·25	*6·48*	35·17	*6·07*	·21	—	—
350 »	—	—	*6·50*(1)	·20(1)	—	—	*6·00*(3)	·22(3)	*6·41*	35·27

(1) 380 metres. (2) 70 metres. (3) 340 metres.

Fig. 87 demonstrates the vertical distribution of *salinity* at Stat. 1 in May, in the years 1901 to 1905. The variations are comparatively small, at least below 100 metres (the exceptional course of the curve of May, 1902, may partly be explained by the more southern position of the station in that year). The greatest difference in the

(1) Published in a Supplement to the *Bulletin* for May, 1905.

salinity, *e. g.* at 200 metres, was only 0·07 ‰. The level of the 35·0-isohaline is indicated by a line in the columns of the table; it differs somewhat in different years; in 1902 it was at about 160 metres, in 1903 at about 95 metres. It is in most cases a little below 100 metres. It is noteworthy that the 35·0-isohaline lies deeper when the surface-temperature is low (1901 and 1902) than when it is high (1903 and 1904). It is obviously an effect of the lateral oscillation; when the sea-surface is heated, the surface water is extended farther seawards, and the deeper strata are lifted accordingly (cf. seasonal variations).

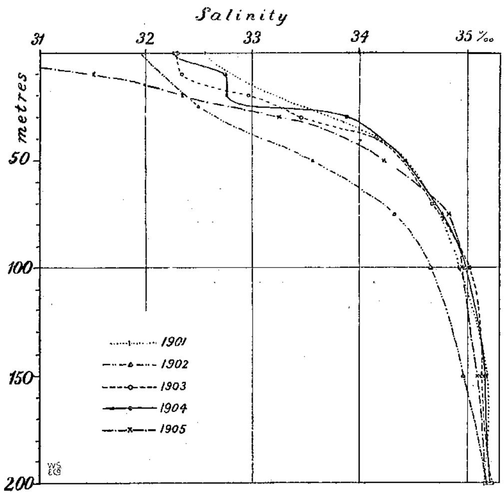

Fig. 87. Curves of Salinity at Stat. 1. in May, 1901—1905.

The *temperature* observations in May from all years show a distinct minimum of between 5 ° and 5¹/₂ ° C, at depths between 30 and 50 metres. A maximum of temperature is found in the upper part of the Atlantic water, at about 150 or 200 metres. The annual variations of temperature are quite appreciable, but not as great as the seasonal variations, wich will be discussed later. The annual variations in intermediate strata, with approximately the same salinity, amount to about 0·5 ° C.

The section of the coast-water seawards from Feje in May of different years will be seen in our Plates (XVI, XVII, XXI A, and XXIV A) or in Figs. 48—52. The shape of the coast-water section differs a great deal; it was deep, and comparatively narrow at the surface, in 1902, and comparatively shallow, but broad at the surface, in 1903. These variations in the shape of the section may be easily explained by the lateral oscillations due to the variations in the temperature (density). But the *area* of the transverse section varies also much. We have already mentioned that the transition from water with salinity below 35·0 ‰ to water with salinity above 35·0 ‰

is rather gradual and often indistinctly defined vertically. The shape of the 35·0-isohaline is therefore not so typical for the variations of the coast-water in a vertical section as that of 34·5 or 34·0 ‰. We have made use of the latter isohaline (of 34·0 ‰) for finding the area of the coast-water section off Feje in different years. We have found the following areas in May (by the planimeter):

Year	1901	1902	1903	1904	1905
Area in square kilom.	3·8	5·2	2·9	6·0	5·0

These variations are quite conspicuous; the area was thus more than twice as large in May, 1904, as in May, 1903. It may seem probable that variations such as these are chiefly caused by preceding variations in the rainfall. Fig. 88 proves the correctness of this assumption. Curve I demonstrates the variations in the coast-water area as given above. II represents the total rainfall per year in Christiania, in percentage of the normal value. III represents the yearly rainfall in Bergen, from 1900 to 1905, in percentage of the normal rainfall. IV shows the mean rainfall anomaly (in percentage of the normal value) for 6 stations in Germany (Bremen, Aachen, Berlin, Breslau, Mannheim, Meersburg).(1) V represents the mean rainfall anomaly (in % of the normal value) for the months of October—December, computed for 25 different stations in eastern and southern Norway. The horizontal scale of Curves II—V is moved one year to the right in relation to I, so that *e. g.* the amount of rainfall in Christiania in 1900 comes below the area of coast-water in May, 1901.

The agreement between the curves in Fig. 88 could not be expected to be better considering that the planimeter measurements cannot be exact as our observation material is not so complete as is desirable. (This is perhaps especially the case in 1901, when relatively few observations were made within the coast-water area.) The conditions are, moreover, very complicated; the volume of the coast-water in May depends upon the discharge from the Norwegian rivers some time earlier, and from German rivers still earlier; but this discharge depends upon the rain of the period, and on the melting of the snow

(1) The mean rainfall at each station for the years 1900—1906 have been reckoned as the normal value for the place; the absolute values are therefore not correct, but our curve gives nevertheless the relation between the different years.

which has fallen perhaps some months before. In order to study the relation between these factors exactly it would be necessary to work up a very large material. We have not found it worth while, as our determinations of the quantity of coast-water are not accurate enough

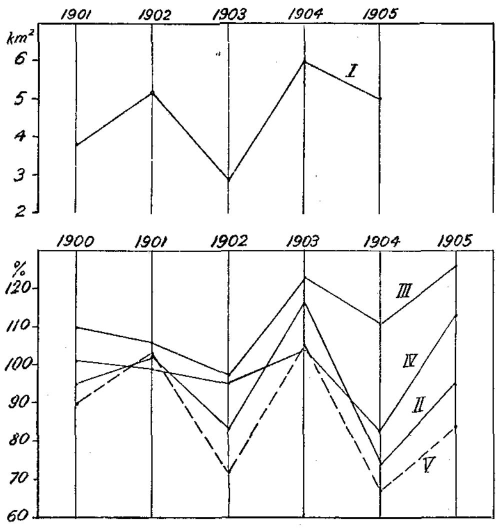

Fig. 88. Curves showing the Variations in: I the Area of Coast Water seawards from Feje, in Square Kilometres; II—IV the yearly Rainfall Anomaly (II in Christiania, III in Bergen, IV in Germany); V the Rainfall Anomaly in Norway, in October to December (incl.).

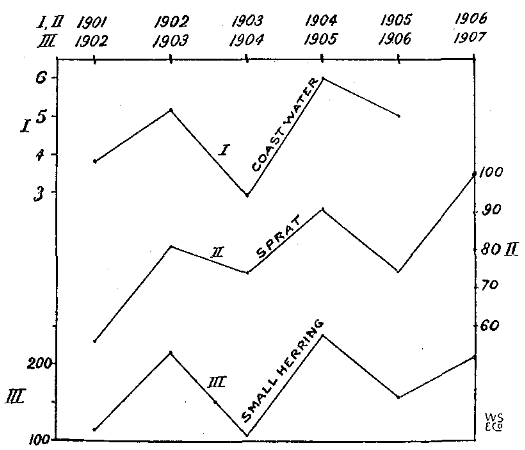

Fig. 89. Curve I demonstrates the Coast Water Area in the Sognefjord Section (in square kilom.), II the total Quantity of Sprat, caught in Norway, and III the Quantity of Small Herring before the first Spawning (in 1000 Hecto-litres).

for a detailed examination. As it is, the curves in Fig. 88 seem, in our opinion, to prove the correctness of our assumption. We may especially call attention to the fact that Curve V agrees better than the others with Curve I; it seems, therefore, as if the rainfall in Norway in the last months of the year are of special importance for the quantity of coast-water off the Sognefjord in the following month of May.

Our observation material from northern Norway (the Lofoten section) is not great enough for drawing trustworthy conclusions as regards the quantity of coast-water in higher latitudes.

Relation between the Annual Variations in the Coast-Water and the Fisheries of Sprat and Small Herring.

It would *a priori* seem very natural that the variations of the coast-water had som influence *e. g.* upon the coast fisheries. We have examined the catches of some species of fish which are caught in the upper water-layers near the shore. Such species are, for instance, the sprat (*Clupea sprattus*), and the small herring (*Clupea harengus*, before the first spawning). The sprat is caught along the southern coast of Norway, especially in the autumn in the districts round Bergen and Stavanger, while the greatest quantities of small herring are, as a rule, fished in northern Norway. We might, then, expect to find some relation between the coast-water in May and the catches of sprat in the same year, whilst the small herring-fishery much farther to the north might be expected to show corresponding variations much later, for instance in the following year. The curves in Fig. 89 have been drawn from this point of view; Curve I represents the area of the coast-water section and is the same as Curve I in Fig. 88. II shows the total quantities of sprat caught in Norway in the same years as the coast-water areas are referred to. III represents the total quantities of small herring caught in the following years. The quantities of sprat and herring are given in thousands of hecto-litres.

The agreement between the curves in Fig. 89 is still better than might be expected. During the period of 5 years, from which there are observations, it is seen that a comparatively small area of coast-water corresponds to small catches, of *sprat* in the same year, and of *small herring* in the following year. As the coast-water variations correspond to the variations in rainfall during the previous year (or autumn), there should be a correspondance between the rainfall of a certain year, and the *sprat*-fishery one year afterwards, as well as the *small herring* fishery two years afterwards. In the statistics of these fisheries, the quantities fished of both species are, unfortunately, mixed for years previous to 1901. We have therefore no data for examining the relation between rainfall and sprat or small herring fisheries in earlier years. But for later years, as far as the statistics are worked up, the agreement is almost complete. The curves in Fig. 88 show that there was an increase of rainfall in Norway from 1904 to 1905; Fig. 89 shows a similar increase of the catches of *sprat* from 1905 to 1906, and of *small herring* from 1906 to 1907. These conclusions are based upon observations of 5 years only, and it may be, of course, that further investigations will give other results. But the coincidence seems to be so striking for the years in question, that it is, in our opinion, not likely to be merely accidental.

Seasonal Variations.

For the study of the seasonal variations of the Norwegian coast-water we shall again turn to Stat. 1, off the Sognefjord, where observations have been made in four different seasons in 1903. The observations at this station were taken at exactly the same place in May and August of that year; they were taken about 5 nautical miles farther to the north in February, and about 16 miles to WNW in November. The observations at Stat. 1 are given in the following table. The level of the 35·0-isohaline is indicated by a line in the columns of salinity.

Station 1 in different Seasons of 1903.

Date . . .	**February,** 9.		**May,** 22.		**August,** 9.		**November,** 18.	
Latitude N .	61° 6′		61° 1′		61° 0′		61° 15′	
Longitude E	4° 15′		4° 10′		4° 10′		3° 56′	
	t° C	S ‰	t° C	S ‰	t° C	S ‰	t° C	S ‰
Surface	*4·83*	33·56	*7·3*	32·30	*13·78*	29·56	*8·7*	33·70
10 m.	*4·89*	·52	*6·97*	·34	*12·04*	33.24	*9·28*	34·87
20 »	*4·95*	·58	*6·27*	·96	*8·56*	34·43	*9·12*	·95
30 »	*4·98*	·58	*5·70*	33·46	*7·06*	·70	*9·09*	·99
40 »	*4·97*	·58	*5·24*	34·18	—	—	—	—
50 »	*5·68*	34·02	—	—	*6·78*	34·96	*9·23*	35·20
75 »	*6·38*	·47	*5·47*(1)	34·67(1)	*7·27*	35·15	*9·02*	·24
100 »	*6·80*	·79	*6·37*	35 02	*6·87*	·14	*9·30*	·30
150 »	*7·23*	35·05	*7·55*	·14	*7·02*	·19	*8·50*	·30
200 »	*7·91*	·24	*7·00*	·23	*6·71*	·20	*7·94*	·23
300 »	*6·32*	·12	*6·48*	·17	*6·38*	·19	(*7·76*	34·85?)
350 »	*6·25*	—	—	—	*6·38*(2)	·23(2)	*6·29*	35·06

(1) 70 metres. (2) 360 metres.

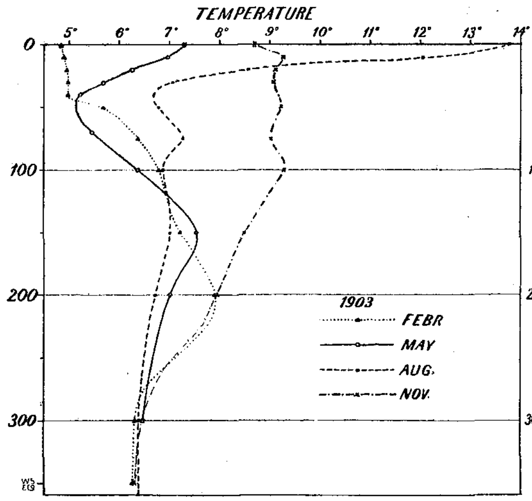

Fig. 90. Curves of Temperature at Stat. 1, in Different Seasons of 1903.

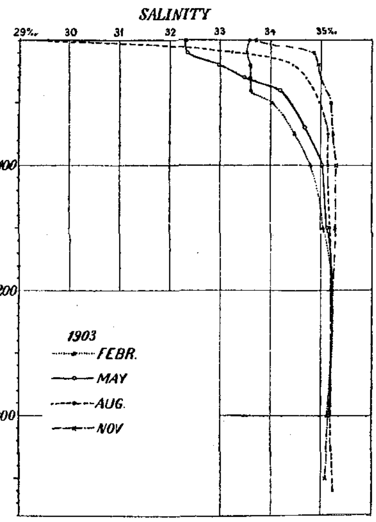

Fig. 91. Curves of Salinity at Stat. 1, in Different Seasons of 1903.

The vertical distribution of temperature in the different seasons of 1903 is demonstrated in Fig. 90. In February, the temperature was almost quite uniform from the surface to 40 metres, with a slight minimum at the surface; the density at the surface was greater than at 10 metres, and convection currents were making the temperatures (and salinities) still more uniform. The temperature was constantly increasing from 50 metres to 200 metres where a maximum of almost 8 °C. was found. In May the surface-temperature was about 2·5 °C. higher than in February, and decreasing downwards to 40—50 metres where a minimum of 5·2 °C. was observed. At 50—100 metres, and again at about 200 metres the temperature was considerably lower in May than in February. In August the surface-temperature was much higher, about 13·8 °C. There was once more a minimum of temperature (6·8 °C.) at 50 metres, and another (6·9 °C.) at 100 metres. At greater depths, down to 250—300 metres, the temperature was still lower than in May. In November the surface-temperature had decreased to 8·7 °C. There where some slight minima and maxima in intermediate strata, but the temperature between 20 and 200 metres was much higher than in the other seasons of the same year. The following table will show the temperature at different depths in each season:

	February.	May.	August.	November.
Surface	*4·8*	7·3	13·8	8·7
20 metres	*5·0*	6·3	8·6	9·1
50 »	5·7	*5·2*	6·8	9·2
100 »	6·8	*6·4*	6·9	9·3
200 »	7·9	7·0	*6·7*	7·9
300 »	*6·3*	6·5	6·4	—
350 »	*6·3*	—	6·4	*6·3*

The minimum temperature at each depth has been printed in *italics*; the minimum temperature of the surface strata occurred in February, of the strata at 50—100 metres in May, at 200 metres in August, and the minimum temperature of the deepest strata occurred in November and February. This shows very clearly, how the "winter" in the sea is proceding downwards, and is for instance met with at 200 metres in August, and near the bottom in the following winter. The amplitude is great at the surface (at least 9° C.) and decreases with the depth. At the bottom it seems to be very slight indeed, in 1903 only 0·1—0·2° C. The temperature must chiefly depend upon the season; but the variations in the currents have also an appreciable influence upon the temperature, as was probably the case in November, 1903, when there was much Atlantic water. We have, unfortunately, no sufficient observation-material from other years for the study of the seasonal variations of the coast-water.

Fig. 91 demonstrates *the vertical distribution of salinity* in different seasons of 1903 (cf. the table p. 154). There is a distinct minimum of salinity at the surface in August (29·56 ‰), and a maximum in November (33·70 ‰). It is a general rule that the lowest salinity occurs in the summer and the highest in the winter. It has been observed by DAMAS [1909, p. 234], that a great number of southern (Atlantic) plankton organisms (such as *Salpae*, *Arachnactis*, *Physophora*, etc.) arrive at the west coast of Norway in the autumn, probably in every year. It may indicate an influx af Atlantic water towards the coast in that season, which is in accordance with the increase of salinity. This influx of Atlantic water may be caused either by an actual progress due to an increase eastwards of the Atlantic Current, or — which is more likely — by the narrowing of the coast-water due to the lateral oscillation that we have mentioned several times above.

It was at first observed by HJORT and GRAN [1899] that the waters off the south-western coast of Norway exhibited certain periodical oscillations, causing *e. g.* the 35·0-isohaline to rise nearer towards the surface in summer than in winter, when it was found considerably deeper. These changes are clearly demonstrated by our observations from 1903. It is, however, remarkable that in November the depth of the 35·0-isohaline was only some 30 metres; it may partly be due to the north-eastern position of the station as compared with the other seasons; but it is probable that the quantity of coast-water has been exceptionally small in November, 1903, and that the said isohaline therefore was met with at a higher level than normal. During the four seasons from which we have observations, the depth of the level at which the 35·0 water is observed, is continually decreasing, and we find consequently an increase of salinity in the intermediate layers, *e. g.* at 100 metres. The variations in the salinity at 100 metres will therefore be reversed as compared with the variations at the surfaces, maximum being found in summer, and minimum in winter. Or, in other words, the coast-water is wide but shallow in summer, and narrow, but deep in winter; the 35·0-isohaline has an oblique course in winter, while in summer it runs more parallel to the surface. By means of our sections we find the following distances from the coast to the boundary, on the surface, between the coast-water and the Atlantic water:

February.	May.	August.	November.
93	104	187	70 kilometres.

These figures elucidate very clearly the lateral movement of the coast-water. The distance from the coast to the Atlantic current was more than twice as large in August, as in November or February.

We have already stated that this lateral oscillation is chiefly caused by the variations in the density of the coast-water in relation to that of the Atlantic water (p. 225 *et seq.*). It is of great importance, amongst other things, for the distribution of neritic plankton-organisms, *e. g.* the eggs and larvae of many fishes, the medusae, etc. It is in perfect accordance with the fact that these organisms have a much farther seaward distribution in summer than in spring or autumn.

The coast-water has a component seawards in summer, and towards the land in winter, while during the year on the whole, it is moving northwards along the coast. A certain volume of water, which is close to the west-coast of Norway in the early spring will therefore move obliquely away from the coast, towards the north and northwest and attain its farthest seaward extension in the late summer-months; afterwards it will again approach the coast, which it may perhaps reach at some high latitude. These are the great features of the movement of a certain volume of coast water; but it is of course subject to very many variations, *e. g.* on account of numerous vortex-movements.

The lateral oscillation is a general phaenomenon, which will be met with at any coast, not only the coast of Norway. The oceanographic investigations, for instance, in the North Sea, and in the Iceland waters, have proved the existence of quite similar periodical movements of the surface-waters.

IX. Polar Currents.

A memoir on the Oceanography of the Norwegian Sea would be very incomplete without a description of the Polar Currents running into it, as especially one of them, the East Greenland Polar Current with its branches, is of such signal importance for the circulation of this sea, and has such a very great effect upon its physical conditions that they could not be understood without some knowledge of the nature of those currents.

It will therefore be necessary to describe them, although the observations collected during the cruises of the *Michael Sars*, were only on a few occasions taken in the region of the Polar currents. Our discussion must consequently be based chiefly upon observations that have been otherwise collected. We may especially mention the valuable material of surface-observations collected from the Arctic seas by sealing and whaling captains during the various years. Of late years observations which are very important for an understanding of the Polar currents, have been taken, especially by Capt. ROALD AMUNDSEN in 1901 [NANSEN 1906] and by the *Belgica* Expedition under the Duke of ORLEANS in 1905 [HELLAND-HANSEN and KOEFOED 1909].

Polar Water.

Nansen [1902] has described the surface-layer of Polar water, which covers the North Polar Basin to an average depth of about

200 metres, having temperatures between 0° and —1·8° C.(1), and salinities from about 30 ‰ near the surface to about 34·7 ‰ at 180 or 200 metres (where the temperature is about 0° C.). Such surface-layers of cold water occur in all North Polar seas. They are formed by an intermixture of the water from precipitation, chiefly the river-water running into the North Polar Sea and the seas washing Northern Europe (the quantity of precipitation over the northern seas themselves is much less), with the sea-water running into the northern seas from the south. The Polar water is consequently a typical *coast-water*, similar to that carried by the Baltic Current into the Norwegian Sea, only with a lower temperature.

As the surface-layers of Polar water are lighter than the underlying water, on account of their comparatively low salinities, they cannot sink, even though they may be cooled to the freezing-point of the sea-water; and they will thus acquire very low temperature in the uppermost strata, without any appreciable vertical circulation being started. This is the reason why the surface-layers of the Polar seas offer very favourable conditions for the formation of ice. The formation of ice, however, causes an increase in the salinity of the surface-water and as this becomes gradually heavier, may ultimately start a considerable vertical circulation [cf. NANSEN 1902, and especially 1906].

As the sea-water, by contact with the ice, is cooled to the freezing-point of water with a corresponding salinity, and as on the other hand the salinity of the Polar water increases from the surface downwards, it is to be expected that contact with the under-side of the many great hummocks which descend far below the general lower level of the rough ice, will cause the temperature of the Polar water to gradually decrease downwards from the surface to the greatest depths to which the hummocks generally descend at no very great distance from each other [cf. NANSEN, 1906, p. 72, note 2]. If we suppose

(1) According to Dr. BLESSING'S observations [NANSEN 1902, pp. 127—129, 253—254] the minimum temperatures at depths of 40 and 60 metres should have been —1·88 and —1·90° C. But as these temperatures are below the freezing-point of the water *in situ*, they are evidently somewhat too low, and we may assume that the minimum temperature very rarely sinks below —1·85° C.

the latter depth to be about 60 metres in the North Polar Basin,(1) and the salinities as given in the following table, we should find the following temperatures at the different depths, provided that the water was cooled to its freezing-point *in situ* (*i. e.* exposed to the pressure of the overlying water).

Depth in Metres	0	20	40	60	0	20	40	60
Salinity ‰	30·00	31·50	33·00	33·70	32·00	32·50	33·50	34·00
Temperature ° C.	— 1·66	— 1·73	— 1·83	— 1·88	— 1·74	— 1·78	— 1·85	— 1·90

This table consequently gives the lowest temperatures that are possible at these various depths with the salinities mentioned. The probability is that below 20 metres temperatures as low as above will hardly ever be found if the salinities be no higher, because that part of the water, which has been in contact with ice, and has been cooled down to freezing-point, has been mixed with water, which has not been in contact with the ice. Nevertheless temperatures approaching those of the above two series will generally be found wherever ice and the typical conditions of the Polar water occur (*e. g.* in the North Polar Basin, or in the East Greenland Polar Current, or in the cold surface-layers of the Barents Sea [cf. NANSEN, 1906, pp. 55, 139—141, 145]); and there is as a rule a minimum at depths between 40 and 60 metres.(2)

(1) The great hummocks of the North Polar ice rise to about 6 metres or 7 metres (or sometime even 8 metres) above the water-surface, and probably descend to 60 metres or more below the surface, provided that the shape under water is not much broader than that above. Isolated pieces may even descend much deeper. The buoyancy of the North Polar ice is considerably less than that of glacier ice, or fresh water ice, because it is very porous, and the pores are filled with brine, the salinity of which varies with the temperature of the ice.

(2) Another kind of minimum of temperature may be formed outside the region of the typical Polar water. By the cooling of the sea-surface and the vertical circulation during the winter the upper water strata may become very cold and nearly homogeneous down to a certain depth at the end of the winter. By the heating of the sea-surface and the metting of ice in the summer the temperature is raised and the salinity lowered in the upper strata, and a minimum of temperature may then be found in the deepest strata to which the vertical circulation from the surface descended during the preceding winter [cf. HELLAND-HANSEN and KOEFOED, 1909].

At depths below the level of this minimum, the temperature again gradually increases downwards, at first slowly, then more rapidly, towards the temperature of the underlying varmer water-layer with temperatures above 0° C. and salinity above 34·7 or 34·8 ‰. The isotherm of 0° C. may be taken as marking the boundary between the two layers. Its depths may vary in the different regions of the sea. Along the *Fram's* route through the North Polar Basin it was found at depths varying between 170 metres and 220 metres (or even 250 metres).

The above general features of the vertical distribution of temperature and salinity are typical for all North Polar or Arctic Currents carrying Polar or Arctic water. The explanation of the intermediate warmer layer which almost everywhere (also in the Antarctic) occurs between the top layer of cold Polar (or Arctic) water and the cold bottom-water filling the deeper parts of all northern seas, is that there is a gap in the density between the lighter Polar waters with comparatively low salinities and the much heavier bottom-water; warmer waters with densities corresponding to this gap, will therefore find their way from the adjacent seas in between these two kinds of water which are entirely different both in nature and origin [cf. NANSEN, 1906].

We may distinguish between three Polar currents running into the Norwegian Sea, *viz. the Bear Island Arctic Current*, the *Spitsbergen Polar Current*, and the *East Greenland Polar Current.*

1. The Bear Island Arctic Current.

By this name we call the narrow cold current, running westwards and south-westwards into the Norwegian Sea south of Bear Island. It comes from the northern Barents Sea and follows the southern slope of the Bear Island Bank along the north side of the Bear Island Channel (cf. NANSEN, 1906, Pls. II & III, see also our Pl. XIII). The volumes of water carried by this current are evidently not very considerable. They are composed partly of cold Arctic water from the northern Barents Sea, with temperatures below 0° C. or even below – 1° C., and with salinities below 34·7 ‰—and partly of somewhat warmer water with higher salinities arising from an intermixture of the cold water with the water carried by the North Cape Current.

Our only station taken in the middle of this current is Stat. 61, on September 4th, 1900, (see Pl. III, and the section, Pl. XIV A, Fig. 3). Between depths of 20 metres and the bottom at 90 metres, the temperatures were below 0 ° C., between 30 and 50 metres below —1 ° C., and the salinity rose downwards from 34·00 ‰ at 20 metres, to 34·72 at 90 metres. At Stat. 60, a little farther south, both temperatures and salinities were somewhat higher (see Pl. XIV A, Fig. 3).

In March, 1901, a similar section was taken, but there was no station so near Bear Island as to be actually in this narrow current. Stat. 24 (Pl. XV, Fig. 4) was just on the boundary of it, however, as the section shows.

The inclination of the isopyknals in these two sections from September, 1900, and March, 1901, do not, however, indicate any rapid westward movement of the waters of this current, unless we assume that the bottom-layers have been moving with almost the same velocities as the surface-layers. But if there had been more stations in the current, the section would probably have had a different appearance. The inclination of the isopyknals in both sections also proves that this Arctic current must be very narrow, as nearly all the water filling the opening between Norway and Bear Island was evidently moving eastwards, with comparatively great velocities near the surface.

We consider it probable that this current is nearly always running westwards along the southern slope of the Bear Island Bank; but being so small and narrow, it is naturally subject to great variations, and its waters may easily be more or less mixed with other waters. It is probable that this current helps to form a kind of eddy or cyclonic vortex-movement in the sea south-west of Bear Island, as was mentioned above.

This current, though insignificant, may nevertheless be disagreeable for navigation, as it often carries ice far towards the south-west of Bear Island.

2. The Spitsbergen Polar Current.

This current runs round South Cape on Spitsbergen, and northwards along the west coast, inside the Spitsbergen Atlantic Current. It flows south-westwards along the south-east coast of Spitsbergen (and

Edge Island). We know very little about the course and nature of this current, but it probably follows the depressions of the continental shelf between Spitsbergen and the Bear Island and Hope Island Bank (cf. Pls. I & XIII). As, however, the waters over this shelf are very shallow, hardly above 100 metres in depth, we cannot expect the current to be deep; and in fact it is chiefly a surface-current. It carries Polar or Arctic waters with temperatures below 0 ° C. and comparatively low salinities, but they are evidently to a very great extent already intermixed with Atlantic water before they reach South Cape. Its surface salinities vary in summer between 32·0 and 34·0 ‰ [cf. NANSEN, 1906, Pl. I; HAMBERG, 1906, p. 28, Pl. II], but in winter are probably much higher, owing to the formation of ice.

No good station was ever taken in this current, so we know hardly anything about its depth and the vertical distribution of temperature and salinity. The Station G (76 ° 40′ N. Lat., 23 ° 12′ E. Long) of the Nathorst Expedition, June 24, 1898 [HAMBERG, 1906, p. 37], was probably on its outskirts. The temperature decreased from 2·3 ° C. at the surface, to a minimum of 0·2 ° C. at 50 metres, or very nearly the same depth at which there is a minimum in the North Polar Basin and in the East Greenland Polar Current [cf. NANSEN, 1902, 1906]. From this minimum the temperature again increased downwards to 1·7 ° C. near the bottom at 127 metres. The salinity increased downwards from about 34·04 at the surface to about 34·89 ‰ at the bottom.(1) It is probable that we should find a similar vertical distribution in the middle of the current, only with lower temperatures and salinities.

At HAMBERG's Stat. F (77 ° 25′ N. Lat., 27 ° 30′ E. Long.) the temperature decreased from — 0·3 ° C. at the surface (and 33·0 ‰) to a minimum of — 1·7 ° C. at 30 and 50 metres below the surface. The salinity at 30 metres was 33·86 ‰, and at 50 metres 34·12 ‰. At 100 metres there was — 0·8 ° C. and 34·33 ‰, and at the bottom at 160 metres — 1·5 ° C. and 34·96 ‰. We consider it probable that the last mentioned, very cold layer was local bottom-water of the kind characteristic of the Barents Sea [cf. NANSEN, 1906, pp. 20 *et seq.*],

(1) We have reduced HAMBERG's values of salinity by 0·05 ‰ in order to make them harmonize with others computed by Knudsen's Tables (cf. above p. 16).

which had been formed during the winter—by the cooling of the sea-surface and by the formation of ice—and had sunk to the bottom. This is also proved by its high salinity. Thus it did not belong to the water of the surface current. Is is doubtful, in our opinion, whether this Stat. F was actually in the area of the Spitsbergen Polar Current, or whether it was not rather to the south-east of it. It is possible that the waters at this place run more southwards along the slope of the Hope Island Bank, and join the Bear Island Current.

ROALD AMUNDSEN's two Stations 24 and 25 near King Charles Land, also show low temperatures [cf. NANSEN, 1906, p. 55], and at Stat. 24 there is also a cold bottom-layer at 150 metres (of — 1·79° C. and 34·61 ‰).

Stat. 338 (76° 16′ N. Lat., 17° 49′ E. Long.) of the Norwegian North Atlantic Expedition [MOHN, 1887, p. 58] was evidently south of the Polar Current, south-east of South Cape. There was a minimum of 1·7° C. at 73 metres, but otherwise the temperatures between 0 and 183 metres were above 2° C. At depths greater than 219 metres the temperatures were below 0° C., at 238 metres and at the bottom at 267 metres even about —1° C. This cold bottom-layer was evidently not brought by the Spitsbergen Polar Current, but was local bottom-water (or winter-water) of an origin similar to that mentioned above, at HAMBERG's Stat. F. and AMUNDSEN's Stat. 24.

After having rounded South Cape the Spitsbergen Polar Current runs northwards as a coast current close along the west coast of Spitsbergen, between the land and the Atlantic Current, with the waters of which it is gradually intermixed.

This Polar Current greatly affects the navigation on Spitsbergen, as it carries ice along the coast, round South Cape, especially early in the summer. And it is evidently also the cause of the east coast being so often blocked by ice.

3. The East Greenland Polar Current.

Since Nansen wrote his memoirs on "the Oceanography of the North Polar Basin," [1902] and on "Northern Waters" [1906], where he has also described the above current, numerous very important observations have been taken by KOEFOED in or near the region of this current east of northern Greenland, during the expedition of the Duke of ORLEANS in the *Belgica* (with Commander A. DE GERLACHE as captain), in the summer of 1905. This observation-material, described and discussed by HELLAND-HANSEN and KOEFOED [1909], gives much valuable information about the Greenland Polar Current, and we have thus now attained a fairly clear understanding of its most important features in that region. Our Pl. XIII, (which is the same as Nansen's Pl. V, [1906]) was unfortunately printed before we knew of these observations, otherwise the charts of the Plate might have been made more complete.

The East Greenland Polar Current is composed of cold water, with temperatures below 0° C., and comparatively low salinities, which comes from the North Polar Basin, where it forms a surface-layer with a thickness of between 170 and 240 metres(1) [cf. NANSEN, 1902, Pl. XV]. The current runs southwards from the unknown north, along the north-east coast of Greenland, and across the probable submarine ridge between this coast and Spitsbergen. We do not know the depths over this ridge on the Greenland side, but we think it probable that they are comparatively small. The Polar Current follows the edge of the Greenland continental shelf southwards, running with by far its greatest velocity over the continental slope, and only with small velocities in the shallow sea over the floor of the continental shelf. The latter is probably very broad—about 120 naut. miles (or 220 kilometres)—as far north (in about 78° N. Lat.) as the soundings of the *Belgica* give us any information about it; and it has the same width farther south in 76° N. Lat. We think there is some probability that the continental shelf is also comparatively wide north of 78° N. Lat. as this would best explain the conditions of the East Greenland Polar Current, farther south where we know it.

Fig 95 (p. 289) represents a transverse section of the East Greenland Polar Current, in about 76° N. Lat., which gives a good idea of the

(1) This water is really as mentioned above to be considered as coast-water, like that of the Baltic Current, formed by intermixture of river-water, chiefly from Siberia, with the Atlantic water and other water running into the North Polar Basin through the Barents Sea and west of Spitsbergen.

horizontal and vertical distribution of temperature and salinity in this current (see also Pl. XXV, Sect. IV). The section passes from the *Belgica* Station 36a, in 76° 37′ N. Lat., 18° 22′ W. Long., along 8 stations of the *Belgica* (see Fig. 94) and through AMUNDSEN's Stats. 23, 22, 18, 13, and 15 to RYDER's Stat. VIII. The section passes along straight lines from Stat. 36a to 30 of the *Belgica*, and from the latter station to AMUNDSEN's Stat. 13, and thence to RYDER's Stat. VIII. The other stations have been projected on these lines, parallel to the main direction of the current (cf. Fig. 94).

As AMUNDSEN's stations were taken in June and July, 1901, the *Belgica* stations in July, 1905, and RYDER's station in July, 1891, the section does not give an accurate representation of the conditions in either of these years; but the general great features are certainly much the same every year in this region, and we may therefore assume that the section gives a trustworthy representation of the main features of the horizontal and vertical distribution of temperature, salinity, and density in the East Greenland Polar Current, as also in the cold "central region" outside (at AMUNDSEN's stations) in the summer.

A very striking feature in this section is the nearly horizontal direction of the equilines over the continental shelf, and their sudden rise near its edge and over the continental slope, between Stats. 30 and 29a. The steep inclination of the isopyknals between these two stations proves that the southward transportation of water by the current takes place chiefly along the edge of the shelf and over the continental slope; while the southward movement over the continental shelf is comparatively insignificant, as has been pointed out by HELLAND-HANSEN and KOEFOED [1909]. The explanation of the latter fact may be that the floor of the shelf is probably very uneven.

It is very possible, and even probable, that the *Belgica* stations of our section have been in a submarine valley or fjord (cf. Pl. I), and that to the north of them there has been a higher ridge or plateau rising to within between 100 and 200 metres of sea-level. There is a sounding of 183 metres indicating such a plateau or ridge to the south (Pl. I), and the *Belgica* soundings farther north, north of 78° N. Lat., also indicate a high general level of the continental shelf, soundings of 100, 78, and even 58 metres being taken far from land, and outside much deeper soundings, of 490 and 530 metres, in another submarine fjord. It is also in conformity with the general features of other continental shelves [cf. NANSEN, 1904] that the general level of this continental shelf, where it is not intersected by submarine fjords, is between 100 and 200 metres below sea-level, or even higher if it is built up of hard primary rocks.

If this be correct, the explanation of the horizontal direction of the isopyknals over the continental shelf in our section is simply that the section has passed along a submarine fjord, where the greater part of the water has been below the level of the ridge on the northern and southern side of this fjord. The water may either have had very little motion, or it may have been moving along the fjord in the direction of the section. It thus seems quite natural that there should not be any great general movement in a southward direction of the water over the continental shelf. The main body of the southward current must run along the edge of the continental shelf where there are no transverse ridges to stop it; and owing to the considerable deflective effect, which the Earth's rotation has in these high latitudes, the current will be pressed close against the continental slope on the right hand side of the motion.

As the velocities are certainly much greater in the surface-layers than in the deeper strata, the water near the surface must be pressed hard towards the right, and the lighter surface-strata must become much deeper on that side of the current.

The equilines must therefore acquire the shapes that we see in the section, with steep inclinations near the edge of the shelf and over the slope, and hardly any inclination over the shelf. Farther seawards, towards the region of AMUNDSEN's Station, there is evidently also very little motion, as might be expected. The conditions are similar to (although in a way even simpler than) those we found in the Atlantic Current off the Norwegian Coast, where the northward movement was also chiefly limited to the continental slope and the edge of the continental shelf, while the motion was comparatively slow over the shelf.

HELLAND-HANSEN and KOEFOED [1909] have calculated the velocities of the waters moving southwards between Stat. 29 b and 29 a, and leaving friction out of account, they have found that the difference in velocity between the various strata was as follow:

Difference	between	surface	and	50	metres	was	3	cm.	per	second
»	»	»	»	100	»	»	11	»	»	»
»	»	»	»	200	»	»	20	»	»	»
»	»	»	»	300	»	»	22	»	»	»

As friction has not been taken into account, the values of velocity are somewhat too small. If we assume that the movement has been very slow at 300 metres, we may conclude that the velocity of the surface-current at this place has been 25 cm. per second or somewhat more. But as the water at 300 metres was probably also moving southwards, the surface velocities have been greater.

From the observations at two stations farther north HELLAND-HANSEN and KOEFOED have computed the differences of the velocities of the southward-moving water strata between these stations to be as follows:

Difference	between	velocity	at	surface	and	at	50	metres	was	16	cm. per	second
»	»	»	»	»	»	»	100	»	»	24	» »	»
»	»	»	»	»	»	»	200	»	»	30	» »	»
»	»	»	»	»	»	»	300	»	»	30	» »	»
»	»	»	»	»	»	»	400	»	»	30	» »	»
»	»	»	»	»	»	»	600	»	»	31	» »	»
»	»	»	»	»	»	»	800	»	»	32	» »	»

The values found in this case may have been somewhat too great, as the section was not transverse to the direction of the current, and it was therefore assumed that the angle between the section and the current-direction was 30°; but this angle may have been greater, in which case the values obtained would have been smaller. On the other hand if friction had been taken into account, this would have increased the values. Provided that the movement of the water has not been considerable at 800 metres, we may assume that the velocity of the surface-current along the edge of the continental shelf off Greenland was between 25 and 32 centimetres per second (12—16 naut. miles in 24 hours). As HELLAND-HANSEN and KOEFOED have pointed out in detail [1909], these values agree remarkably well with the velocities of the ice-drift which Nansen [1890, vol. I, pp. 295, 300] has calculated from the drift of ships with the East Greenland Polar Current, and also with the velocity of drift observed by Commander A. DE GERLACHE during the cruise of the *Belgica* in 1905.

It is a striking fact that, according to both the above series of calculations, the greatest velocities of the current are evidently in the top-layers, between the surface and 200 metres, while there is apparently very little difference between the velocity at 200 metres and that at even 800 metres. At 200 metres at Stats. 29 b and 29 a, we find approximately the boundary between the cold top-layer of Polar water from the North Polar Basin, and the underlying warmer water which has a *different origin*, as will be mentioned later. The actual southward velocity of the latter water cannot be computed as long as we do not know the velocity, *e. g.* at 800 metres; but there is little probability that it is considerable.

We have assumed that the observations at AMUNDSEN'S stations in July, 1901, described by Nansen [1906], and the observations at the *Belgica* stations in July, 1905, represent approximately the usual relation in the distribution of density in this region, although the observations are taken in different years. By using AMUNDSEN'S Stat. 23 (July 11, 1901; 74° 30′ N., 7° 53′ W.) and the *Belgica* Stat. 28 (July 21, 1905; 75° 55′ N., 9° 0′ W.) we have computed the velocity of the current in the sea between these two stations, and have found the following values of *the difference of velocity at the surface and at*

metres	10	20	50	100	150	200	300	500	600	700	800
cm./sec.	0·4	0·7	1·2	2·4	3·3	3·8	4·5	5·7	6·2	6·7	7·0

These values are naturally too low, because the probability is that an observation-station nearer to Stat. B 28 would have given a steeper inclination of the isopyknals and higher velocities accordingly, and also because the line between the two stations runs obliquely to the direction of the current. The angle may have been about 45° in which case the values found should be multiplied by 1·43. It has also to be considered that the friction has not been taken into account, which also makes the values found too low.

The water is at all the above depths lighter at the *Belgica* Stat. 28 than at AMUNDSEN'S Stat. 23. The water should consequently flow southwards with velocities that decrease from the surface downwards as the above figures indicate; but it cannot be decided by computations whether the deep strata flow southwards or northwards, or at which depth eventually the velocity of 0 occurs. The probability is that *all* water down to 800 metres runs southwards, because the density was certainly not smaller at AMUNDSEN'S Stat. 23 than that at Stat. B 28, in the deepest strata where there are no observations.

Our computations indicate that there are probably no great velocities in the outer part of the current between the two stations, as compared with the velocity of the surface current near the continental slope, and they also indicate that there are probably no great velocities in the deeper strata below the level of 200 metres. The difference between the velocities at 200 metres and at 800 metres was according to our former computation (p. 270) only 2 cm. per second, and according to our latter computations 3·2 cm. per second.

If this be correct we arrive at the following conclusion:

The fast southward movement of the East Greenland Polar Current is chiefly limited to the upper 200 metres of the sea, and to a narrow belt along the continental slope. The main body of the current is thus very narrow, and only 200 metres deep, being chiefly composed of cold Polar water, gliding on the underlying warmer water as a floor. The underlying intermediate warm water-layer moves comparatively slowly.

The Horizontal and Vertical Distribution of Temperature, Salinity, and Density within the Cold Water of the Current.

This distribution must be influenced by the movement. As the velocities are greatest at the surface, we must expect the surface-layers of cold Polar water, which are lighter than the underlying water on account of its much lower salinities, to be pressed towards the right, owing to the effect of the Earth's rotation. They will consequently be much deeper on the land-side of the main current, than on its seaward side, where they will be raised and will be comparatively thin. This agrees exactly with the conditions in the section. At Stat. 29 b, just over the edge of the continental shelf, and on the right of the main current, the isotherm of 0° C. descends to about 225 metres, from 135 metres at Stat. 29 a; and the isotherm of — 1° C. descends to about 190 metres, from about 90 metres at Stat. 29 a. The depth of the strata on the right of the main current (at Stats. 29 b and 30) will also approximately determine the depth of the same strata over the continental shelf, where there is comparatively little movement, and where we consequently find a nearly horizontal course of the equilines.

Considering that differences in the movements have such a great effect upon the thickness of the surface-layers, we cannot expect that the several strata of the Polar water will have the same thicknesses everywhere in the East Greenland Polar Current as they have in the North Polar Basin, because the conditions and the movements are very different in the two seas.(1) According to what has been said above, it is to be expected that the strata of Polar water on the right of the current and over the continental shelf would be thicker than in the North Polar Basin, while the contrary will occur on the left (seaward) side of the current. Our section proves that such is the case.

We know the thickness of the strata of Polar water in the North Polar Basin only along the track of the *Fram*, 1893—1896.

In the following Table (pp. 274 & 275) we give the observations from two different localities in the North Polar Basin (and also the means of all stations there), together with the observations at four *Belgica* stations, Stat. 36 a close to the coast, Stat. 30 inside

(1) It is also probable that the strata of the Polar water will vary in thickness with the periodical variations in the Polar Current (cf. above, p. 113).

the edge of the continental shelf, Stat. 29 a outside the edge, and Stat. 28 a little farther from it. The last two stations are on the outer side of the main body of the current, while the first two are inside it. The salinities of the *Fram* expedition have been computed from the determinations by hydrometers by means of Knudsen's Tables.

For purposes of comparison we also give some earlier stations in the East Greenland Polar Current from the region just south of the *Belgica* stations, *viz.* two stations from the NATHORST Expedition of 1899 [ÅKERBLOM 1904], two stations from RYDER'S [1895] expedition of 1891, and one station from AMDRUP'S [1902] expedition of 1900. They are all of them north of 74° N. Lat. NATHORST'S Stat. IX is in a submarine fjord between the outer islands (1), while his Station VII (see the sounding of 287 metres in Pl. I), and RYDER'S Stat. XIII (south of it) are near the edge of the continental shelf. RYDER'S Stat. XII and AMDRUP'S Stat. III are in deep water outside the continental slope, and evidently near the outskirts of the Polar Current. The same main features are recognizable in all of these series of observations. At the stations near land, and far within the edge of the continental shelf, the *Belgica* Stat. 36 a and NATHORST'S Stat. IX, the cold Polar water-layers, with temperatures below 0° C. (but with comparatively low density), are deeper than in the North Polar Basin, their lower boundary being somewhere between 250 and 300 metres, while at the stations over the deep sea, outside the continental slope the cold Polar layers are not so deep as in the North Polar Basin. Their lower boundary being raised to about 115 metres at RYDER'S Stat. XII, and even to about 90 metres at AMDRUP'S Stat. III.

At stations over the continental slope, *Belgica* Stat. 29 a, & 28, where the current runs with great velocity, the lower boundary of the cold Polar layer is also somewhat higher (near the level of 150 metres) than in the North Polar Basin. But at the stations near the edge of the continental shelf—cf. especially NATHORST'S Stat. VII, and RYDER'S Stat. XIII—the depth is very nearly the same, namely between 170 end 190 metres(2).

The vertical distribution of temperature and salinity in the cold layer of Polar water exhibits exactly the same general features at all stations in the East Greenland Polar Current as in the North Polar Basin, at the stations of the *Fram* Expedition.

The temperature, salinity, and density at the surface will naturally vary much with the season, owing to the heating of the sea-surface, and the melting of snow and ice in the summer; but below 10 or 15 metres the seasonal changes are very slight.

(1) By an error 395 metres appears in our Pl. I at this Station instead of 305.

(2) We do not here take into account the great vertical oscillatory movements of these strata, which, according to our view, probably occur along the edge of the continental slope (cf. above). These oscillations make it difficult to determine the real thickness of the strata, unless the observations be repeated at intervals for some length of time.

Temperature (° C.), *Salin-*

Depth. Metres.	Fram. July 31, 1895. **23.** 84° 30′ N. 75° E.	 June 25, 1894. **16.** 81° 41′ N. 121° 30′ E.	 Mean of all *Fram* Stations.	**Bel-** July 27, 1905. **36 a.** 76° 37′ N. 18° 22′ W.	 July 22, 1905. **30.** 75° 39′ N. 12° 00′ W.
0	0·16 31·53 25·32	0·34 4·97 03·97	— 0·87 21·10	1·46 31·77 25·46	1·71 31·68 25·36
5	— 1·66	— 1·60 29·69 23·89	— 1·65 29·71	— 1·76 32·22 25·95	1·20 31·72 25·42
10		— 1·62 29·61 23·83	— 1·61 29·85	— 1·20 32·31 26·01	— 0·40 31·88 25·63
20	— 1·79(1) 32·18 25·90	— 1·60 29·81 23·99	— 1·62 30·31	— 1·68 32·60 26·25	— 1·54 32·52 26·18
40	— 1·88(1) 33·32 26·83	— 1·62 32·25 25·96	— 1·72 32·27		
50		— 1·71 33·27 26·78		— 1·89(2) 32·76 26·36	— 1·77 32·96 26·54
60	— 1·88(1) 33 70 27·13	— 1·76 33·66 27·10	— 1·76 33·61		
80	— 1·86 34·03 27·40	— 1·69 33·89 27·29	— 1·74 33·92		
100	— 1·78 34·22 27·55	— 1·58 34·43 27·73	— 1 68 34·04	— 1·80 33·25 26·78	— 1·76 33·54 27·01
150	[— 1·15] [34·49]	[— 0·83] [34·50]			
200	0·43 34·83 27·96	— 0·27 34·83 27·99	0.18 34·80	— 0.92 34·39 27·68	— 0·92 34·46 27·73
250	1 04 34·99 28·05	0·49 35·07 28·14?	0·55 34·97	— 0·12 34·65 27·86	0·55 34·70 27·86
300	1·18 35·01 28·05	0·53 34·97 28·08	0·63 34·98	0·11 34·70 27·89	0·48 34·91 28·03
Bottom in metres	3700	3400		314	375

(1) These temperatures taken by Dr. BLESSING [cf. NANSEN, 1902] with a Negretti & Zambra Reversing Thermometer, are evidently a little too low, as it is not probable that the water was cooled below its freezing-point. The freezing-point for water with the above salinities is — 1·75° C. for 32·18 ‰, — 1·81° C. for 33·32 ‰, — 1·836° C. for 33·70 ‰, and — 1·855° C. for 34·03 ‰ (if computed from M. KNUDSEN'S determinations [1903, p. 13]). As the freezing-point is lowered by pressure, the above temperatures should have been somewhat lower if the water was cooled to its freezing point *in situ*. At 20 metres we should then have found a temperature of about — 1·77° C., at 40 metres — 1·84° C., at 60 metres — 1·88° C.

(2) There must be some error either in temperature or salinity at this depth. The

ity (‰), *and Density* (σ_t).

gica.		Nathorst.		Ryder.		Amdrup.
July 22, 1905. **29a.** 75° 35′ N. 10° 23′ W.	July 21, 1905, **28.** 75° 55′ N. 9° 00′ W.	July 5, 1899. **IX.** 74° 45′ N. 18° 15′ W.	July 1, 1899. **VII.** 74° 38′ N. 5° 3′ W.	July 18, 1891. **XIII.** 74° 17′ N. 15° 20′ W.	July 15, 1891. **XII.** 74° 45′ N. 11° 42′ W.	July 8, 1900. **III.** 74° 9′ N. 11° 31′ W.
— 0·61 31·74 25·53	0·28 31·00 24·90	— 1·50 32·38 26·06	— 0·95 32·54 26·18	— 0·5	— 0·1 32·9?	— 0·2 33·00 26·52
						0·95 33·52 27·07
— 0·75 31·98 25·72	0·08 31·90 25·63			— 1·1	— 0·1	— 1·0 33·68 27·10
— 1·32 32·83 26·43	— 1·30 32·86 26·46		[— 1·1] [33·2]	— 1·3 33·0?	— 0·3	— 1·4 34·20 27·53
						— 1·4 34·52 27·80
— 1·32 34·08 27·43	— 1·73 33·95 27·36	— 1·73 33·19 26·73	— 1·36 34·27 27·60	— 1·8	— 1·1	?
				— 1·9(3)	— 1·0	— 1·05 34·70 27·94
				— 1·3 34·1?		— 0·1
— 0·92 34·37 27·66	— 1·67 34·25 27·59	— 1·59 34·02 27·40	— 1·48 34·63 27·89	— 1·3	— 0·4 34·8?	0·2 34·92 28·05
	0·03 34·56 27·77	— 0·98 34·43 27·71	— 1·00 34·70 27·94	— 1·1	0·4	— 0·1 34·92 28·06
1·41 34·90 27·97	1·32 34·87 27·94	— 0·60 34·69 27·90	0·71 34·97 28·07	0·0 34·8?	— 0·3	— 0·05 34·93 28·07
					— 0·5	— 0·3 34·92 28·07
0·99 34·91 28·00	1·41 34·92 27·96	0·25 34·92 28·05			— 0·6	
1260	1275	305	287	234	1860	?

freezing-point of sea-water with a salinity of 32·76 ‰ should be — 1·783 ° C. (computed from M. KNUDSEN'S determinations [1903, p. 13]) and exposed to the pressure at 50 metres, it would be about — 1·82 ° C. If the salinity of 32·76 ‰ be correct, the above temperature may have been a mistake for — 1·79 ° C. The temperature of — 1·89 ° C. is the freezing-point for water of 34 ‰ salinity (at a pressure of 50 metres of water) which could not occur at that depth, considering that the salinity at 100 metres was 33·25 ‰.

(3) RYDER'S low temperatures are evidently upon the whole somewhat (perhaps 0·1 or 0·2 ° C.) too low [cf. NANSEN, 1906, p. 71]. The probable salinity at this depth, of between 33 and 34 ‰, would hardly give a temperature much below — 1·8 ° C.

As may be expected, the temperatures and salinities of the North Polar water are upon the whole increased in the passage of the water southwards from the North Polar Basin along the east coast of Greenland (cf. our table above). The density of the uppermost strata is also increased. The rise of temperature is partly due to the heating of the sea-surface during the summer, but in the deeper strata it is chiefly due to intermixture with the underlying warmer water-strata, which also causes the increase of salinity. On the other hand the coast-water (river-water and melting glaciers) from Greenland has a tendency to decrease the salinity, raise the temperature, and decrease the density of the upper strata on the inner side of the Polar Current, near the Greenland coast.

The observations at all stations in the East Greenland Polar Current as well as in the North Polar Basin, exhibit a fall of the temperature from the surface-strata to the above-mentioned (p. 262) minimum, which is, as a rule, at a depth of about 50 metres or perhaps 60 metres (cf. the means of all the *Fram* stations; the *Belgica* Stats. 36 a & 30; NATHORST's Stat. IX, RYDER's Stat. XIII).

But at the stations on the left side of the current the level of the minimum is somewhat raised. At AMDRUP's Stat. III the minimum temperature occurs, for instance, at 20 and 40 metres. At the *Belgica* Stat. 29 a the lowest temperature —1·32° C. occurs at 20 and 50 metres; but as this is exceptionally high for 50 metres, it is probable that there has been some admixture of warmer water at this level, this being perhaps also indicated by the comparatively high salinity (34·08 ‰). The minimum (— 1·1° C.) at RYDER's Stat. XII was at depths between 36 and 55 metres.

The level of the minimum was consequently raised at the stations where the level of the lower boundary of the cold Polar layer was also higher(1). This is what we might expect, as all strata of the Polar Current are raised and become thinner on the outer (left hand) side of the current, owing to the deflective effect of the Earth's rotation.

(1) The NATHORST Station VII is an exception as the lowest temperature — 1·48° C. was at 100 metres. But there has evidently been an admixture of warmer and salter water to the Polar water at this station and this admixture may have been more effective in the upper strata than at 100 metres.

The Intermediate Warm Water-Layer underlying the Cold Polar Water.

This intermediate warmer water-layer is of Atlantic origin, and lies between the top-layer of cold Polar water and the floor of cold Bottom-water. It is a very characteristic feature of the conditions in the whole region of the East Greenland Polar Current. The layer was first discovered by Capt. RYDER in 1891, and has since been found by the NATHORST expedition in 1899 [ÅKERBLOM 1904], by AMDRUP in 1900, and by ÖSTERGREN (the *Frithjof* 1900). The observations taken in this current during these expeditions were of a somewhat accidental nature; but during the *Belgica* expedition a number of very accurate observations were taken which give more complete information about the intermediate warm water-layer, showing that it has a greater thickness and extent than might be indicated by previous observations. The *Belgica* observations also prove clearly the correctness of Nansen's view [1902; 1906, p. 74 *et seq.*] that the intermediate warm water occurring in latitudes between 74° and 77° N. comes from the north; and if these observations could have been introduced into the charts for 100, 300, and 400 metres in Pl. XIII, there would have been more room between the isotherm of 0° C. and the Greenland continental shelf between 74° and 77° N. Lat. [cf. HELLAND-HANSEN and KOEFOED, 1909].

The temperatures and salinities observed in the intermediate warm water-layer in different latitudes are in perfect accordance with the view that it is moving from the north southwards along the Greenland continental slope, as both the temperature and salinity decrease with the latitude, as is proved by the following Table (p. 278).

The salinities of the *Frithjof* Station II have been reduced by 0·10 ‰ [cf. NANSEN, 1906, p. 63—64].

There can be no doubt that the intermediate warm water comes chiefly from the region of the *Belgica* Stats. 23, and 26, and flows southwards, covered by the cold water of the East Greenland Polar Current, which causes it to sink deeper. By intermixture with the overlying colder water, its temperature and salinity, on the whole, decrease southwards. Its salinity, for instance, is decidedly lower at the *Belgica* Stats. 48, and 49 (at from 200 to 400 metres), between Greenland and Jan Mayen, than at the *Belgica* stations farther north. The temperatures were also, on the whole, lower than farther north; but at Stat. 48, a temperature of 1·53° C. was observed, at 200 metres, which is higher than any temperatures found at Stats. 26 and 28, but not higher than those at Stat. 23 (2·07 and 1·62° C. at 50 and 100 metres). It is not to be expected, however, that the observations at any of the

Depth in Metres	*Fram*	*Belgica*					*Frithjof*	*Michael Sars*	
	23 84° 30′ N. 75° E. VII 29, 95	**23** 77° 25′ N. 4° 3′ W. VII 17, 05	**26** 76° 29′ N. 4° 54′ W. VII 20, 05	**28** 75° 55′ N. 9° 0′ W. VII 21, 05	**48** 71° 23′ N. 18° 58′ W. VIII 15, 08	**49** 71° 20′ N. 17° 25′ W. VIII 16, 05	**II** 72° 10′ N. 10° 57′ W. VII 26, 00	**18** 69° 9′ N. 12° 0′ W. VIII 6, 00	**13** 66° 55′ N. 8° 48′ W. IX 1, 03
0	0·16 31·5	0·88 32·77	— 0·76 32·35	0·28 31·00	1·65 30·60	— 0·71 30·60	— 0·48 31·0	5·7 34·24	6·18 34·61
20	— 1·79 32·1	3·26 34·82	2·52 34·94	— 1·30 32·86	— 0·54 32·07	— 0·89 32·42	— 1·20 33·83	5·51 34·29	
50	— 1·88 33·50	2·07 34·89	0·77 34·78	— 1·73 33·95	— 1·60 34·14	— 1·66 34·22	— 1·43 34·42	— 1·42 34·57	0·05 34·68
100	— 1·78 34·2	1·62 35·00	1·27 34·97	— 1·67 34·25	— 0·73	— 1·71 34.31	— 0·23 34·78	— 1·01 34·74	— 1·10 34·73
150				0·03 34·56					— 0·47 34·85
200	0.43 34·8	1·11 34·99	1·12 34 98	1·32 34·87	1·53 34·86	1·08 34·86	0·80 34·96	0·63 34·94	0·21 34·90
300	1·18 35·0	0·66 34·98	0·56 34·94	1·41 34·92	1·00 34·93		0·35 34·95	0·24 34·94	0·06 34 96
400	0·99 34·9	0·24 34 95	0·21 34·95	1·03 34·92	0·67 34·94	0·78 34·89			— 0·16 34·95
500	0·73 35·0	— 0·59 34·92					0·52 34·95		
600	0·56 35·0	— 0·77 34·94	— 0·24 34·93	0·44 34·92	0·08 34·92	0·19 34·93		0·41 34·93	
800	0·12 35·0		— 0·50 34·92	0·10 34·93	— 0·30 34·91	— 0·25 34·92			

stations have happened to be taken in the warmest part of the intermediate warm water. Just as the above mentioned temperature of 1·53° C, at Stat. 48, is much higher than the highest temperature (1·08° C.) observed at Stat. 49, of the same section, so it is probable that there has been much warmer water in this current in about 76° N. Lat., than is shown by the observations at Stats. 26 and 28. We may therefore assume that the warm water at 200 metres at Stat. 48 (with 1·56° C. and 34·86 ‰) has come from the north, like the intermediate warm water at Stat. 49.

At the *Frithjof* Stat. II and the *Michael Sars* Stat. 18, the temperatures of the intermediate layer are still lower, but the salinities are considerably higher (1) than at Stat. 48 and 49. It is possible that this higher salinity is due to water coming in from the east, north or south of Jan Mayen; but the comparatively low temperatures incline us to believe that the water has come from the north. At the *Belgica* Stat. 50 an observation was taken in the intermediate warm water-layer, at 200 metres (cf. Fig. 96, p. 290) which gives values just between those at the *Belgica* stations to the west and the *Michael Sars* Stats. 19, 20, 18, and the *Frithjof* Stat. II farther east, as the following Table shows:

	B **48**	B **49**	B **50**	F **II**	M S **19**	M S **20**	M S **18**	M S **13**
200 metres	1·53	1·08	1·00	0·80	0·25	0·25	0·63	0·21
	34·86	34·86	34·91	34·96	34·89	34·89	34·94	34·90

It is hardly possible that the warm intermediate water at these *Belgica* stations can have come from the east. The water found at 200 metres at Stats. *M S* 19 and *M S* 20 is not quite comparable with the water at the same level at the other stations, because the surface-layers are evidently on the whole somewhat depressed near Jan Mayen, and become thicker there, this being also proved by the AMDRUP Stat. II west of Jan Mayen, where exactly the same temperature and salinity (0·3° C., 34·89 ‰) were obtained for 200 metres [cf. NANSEN, 1906, Pl. IX]. The salinity of 34·89 ‰ therefore, belongs to a water-stratum which at other stations lies somewhat higher.

At the *Michael Sars* Stat. 13, of September 1, 1903 (see Fig. 99) we have probably a remnant of the intermediate warm layer underlying the Polar water to the north-west.

The similarity between the temperatures and salinities at the various depths at the *Fram* Stations (*e. g.* Stat. 23) and the *Belgica* Stat. 28 (which is typical for the East Greenland Polar Current, see above) is striking, and there is a possibility of the intermediate warm layer at the latter station having to a great extent come from the North Polar Basin. We do not, however, consider this probable; we think rather that the intermediate warm layers at the *Fram* Stations

(1) The determinations of the salinity of the water at the *Frithjof* stations are somewhat uncertain. The values given in the table above, have been obtained by reducing the original values given by PETTERSSON and ÖSTERGREN [1901] by 0·10 ‰.

in the North Polar Basin and the *Belgica* Station in the East Greenland Polar Current, have the same origin, both coming from the Spitsbergen Atlantic Current, which sends out one branch westwards, which sinks under the Greenland Polar Current, and another branch into the North Polar Basin, this branch sinking under the Polar surface-layer (cf. Fig. 93). This gives a natural explanation of the fact that the intermediate warm layer has such very similar characters in such widely separated regions, as the *Fram* Stat. 23 and the *Belgica* Stat. 28; they are neither of them very far from the common source, the warm current west of Spitsbergen [cf. HELLAND-HANSEN and KOEFOED, 1909]. Down to a depth of about 300 metres there is a good agreement between the salinities obtained by the *Fram* determinations and those of the Belgica. But below this depth the salinities of the *Fram* become markedly higher. The cause may be that the intermediate strata at the *Belgica* stations come from the western part of the Spitsbergen Atlantic Current, which has got a lower salinity by intermixture with "central waters" or Arctic water, while the less intermixed central part of this current runs into the North Polar Basin.

That the intermediate warm layer underlying the cold water of the East Greenland Polar Current, chiefly comes from the Spitsbergen Current is proved not only by the observations at the *Belgica* Stat. 23, but also by observations taken in other years at three stations in the same region, *viz.* the NATHORST Stat. *N*, July 28, 1898, in 77° 52′ N. Lat., 3° 5′ W. Long., the NATHORST Stat. *O*, July 29, 1898, in 78° 13′ N. Lat., 2° 58′ W. Long. [cf. HAMBERG, 1906], and the *Frithjof* Stat. I, July 8, 1900, in 77° 11′ N. Lat., 0° 55′ W. Long.

Depth	0	20- 25	50	100	200	300	500
B 23	0·88 32·77	3·26 34·82	2·07 34·89	1·62 35·00	1·11 34·99	0·66 34·98	− 0·59 34·92
Nath. *N*	3·6 34·33	2·8 34·70		34·98			1·0
Nath. *O*	3·1 33·73	2·9 34·51	2·1 34·88	1·9 35·00			1·1 35·00
F *I*	1·40 33·34	0·45 33·85	− 0·03 34·80	1·04 34·97	1·02 34·99	0·33 34·95	− 0·32 34·94

The values of salinity have been reduced by 0·10 ‰ at Stats. Nath. *N* and F *I*, and by 0·08 ‰ at Stat. Nath. *O*, according to the errors in the salinity of the bottom-water at these stations.

The similarity of the warm waters at intermediate depths, 50 to 300 and 500 metres at these stations, is striking, and makes it highly probable that just in this region there is a continuous inflow of warm water from the north-east, *i. e.* from the Spitsbergen Atlantic Current.

South and south-south-east of this region is the central area of the cyclonic movement of the northern Norwegian Sea, where the cold bottom-water is formed, and where there is no intermediate warm water-layer, as was proved by the AMUNDSEN Stations 13 to 23, (and also by the RYDER Stations IX and X) described by Nansen [1906].

Fig. 93 demonstrates the southward course of both the intermediate warm water and the Polar water. The charts are somewhat different from those of Pl. XIII, because the observations of the *Belgica* expedition of 1905, as also the NATHORST Expedition of 1898, could be utilised.

The Vertical Distribution of Temperature and Salinity in the Region of the East Greenland Polar Current.

It is remarkable how very similar *the vertical distribution of temperature* is in all regions of the Polar Current from the North Polar Basin and as far south as between Iceland and Jan Mayen, or even north-east of Iceland. And this similarity is striking, not only in the top layer of real Polar water, but also in the underlying warmer water.

In Fig. 92 we have drawn the vertical temperature curves for the *Fram Stat.* **23** (July 20—31, 1895), the *Belgica Stats.* **28** (July 21, 1905, 75° 55′ N. Lat., 9° 0′ W. Long.), **30** (July 22, 1905, 75° 39′ N. Lat., 12° 0′ W. Long.) and **49** (Aug. 16, 1905, 71° 20′ N. Lat., 17° 25′ W. Long.), and finally the *Michael Sars Stat.* **18** (Aug. 6, 1900, 69° 9′ N. Lat., 12° 0′ W. Long.) and *Stat.* **13** (Sept. 1, 1903, 66° 55′ N. Lat., 8° 48′ W. Long.)

The similarity of the curves of these several stations so far apart is striking. In the upper strata, between the surface and 100 metres, the curve of the *Fram* Stat. 23 shows lower temperatures than any of the other curves from stations farther south, as might be expected. But below 100 metres the curve of the *Belgica* Stat. 30 shows lower temperatures than the *Fram* curve, while the curve of the Belgica Stat. 28 shows higher temperatures. The *Fram* curve lies between the two *Belgica* curves, a circumstance which is in accordance with what was said above, the curve of Stat. 28 being from the current outside the continental slope, while Stat. 30 was within the edge of the continental shelf.

Down to a depth of about 800 metres there is a striking similarity between the curves of the *Fram* Stat. 23 and the *Belgica* Stat. 28, the main difference only being that the under side of the cold top layer was about 25 metres higher at the *Belgica* Station than at the *Fram* Station. Below 800 metres, the *Belgica* curve indicates lower temperatures than the *Fram* curve, which is in accordance with the fact that the bottom-water is colder in the Norwegian Sea than in the North Polar Basin, as was proved by Nansen [1902; 1906].

The curve of the *Belgica* Stat. 49, in the Polar Current between Greenland and Jan Mayen, is very like the curve of the *Belgica* Stat. 28, four degrees and a

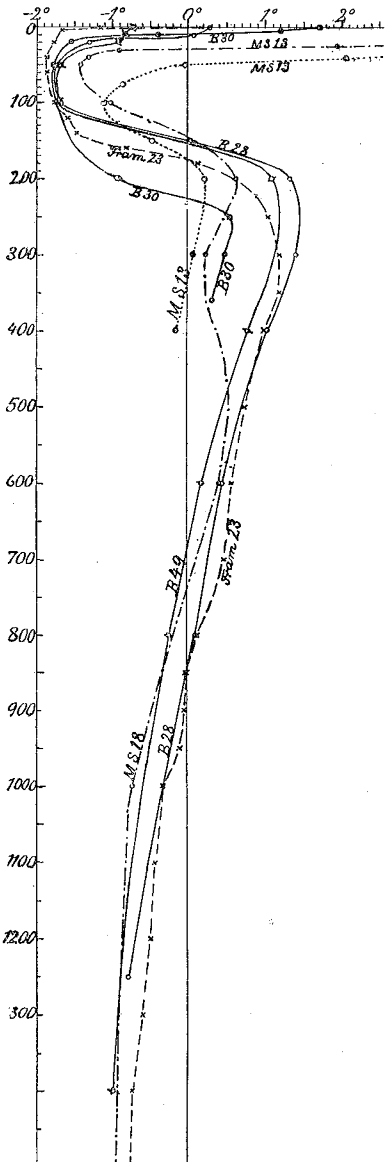

Fig. 92. Temperature-Curves, at Stations from different Parts of Polar Current.

half farther to the north. In the upper part, above 150 metres, the two curves are nearly indentical; but below that level the southern curve (Stat. 49) shows lower temperatures than the northern (Stat. 28).

The *Michael Sars* Stat. 18 was between Jan Mayen and Iceland, and was not really in the Polar Current. The curve of this station shows that the top layer of cold Polar water has become warmer than at any of the above-mentioned stations farther north. It is covered by a surface-layer of warmer water about 25 metres thick; but its lower boundary (the isotherm of 0 ° C.) is very nearly at the same level as at the *Belgica* Stats. 49 and 28. The underlying warmer water is still colder than the *Belgica* Stat. 49 (except at 600 m.), but upon the whole the curve shows a great similarity to that of the last-named station. The curve of the *Michael Sars* Stat. 13, north-east of Iceland, has still the characteristic features of the above curves; but the Polar water has become still warmer and is covered by a thicker layer of warmer water. Its lower boundary is deeper, however, and the underlying water considerably colder than at Stat. 18.

The vertical distribution of salinity and density in the Polar water and underlying warmer water also shows a great similarity in the different Latitudes of the East Greenland Polar Current as also in the North Polar Basin. The similarity in the salinity and density is seen from the above table (pp. 274—275, 278). The determinations of the salinities of the North Polar Basin are unfortunately not sufficiently accurate to show the details of this similarity; but the great features are clear. We shall not enter into further particulars on this point.

Course and Extent of the East Greenland Polar Current.

According to what has been said above, the main body of the East Greenland Polar Current runs southwards along the edge of the continental shelf off the east coast of northern Greenland, and water from this current covers the shelf. The 32·0-isohaline, at the sea-

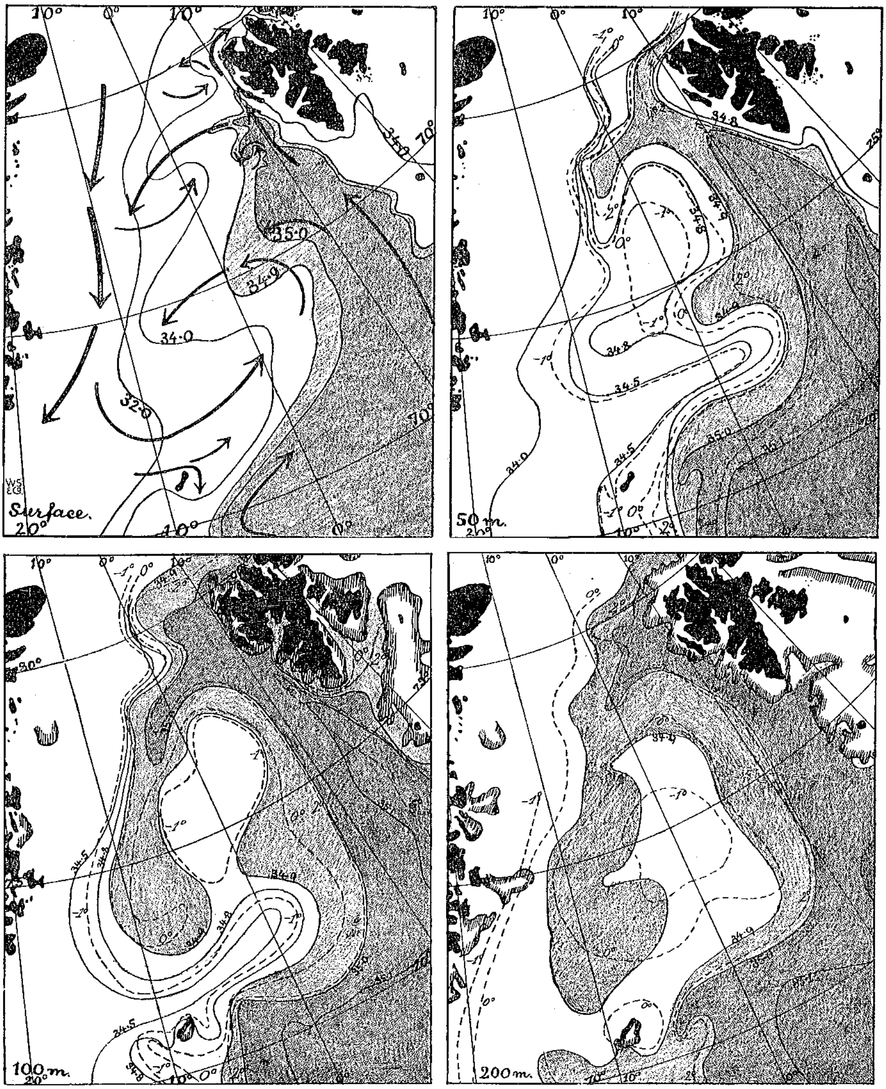

Fig. 93. Horizontal Distribution of Temperature and Salinity in the Northern Norwegian Sea in the Summer, according to Observations made in different Years. The lighter shading indicates salinity from 34·90 to 35·00 ‰, darker shading above 35·00 ‰.

surface, forms a sharply defined boundary-line of the Polar Current. As has been pointed out by HELLAND-HANSEN and KOEFOED [1909], it follows very nearly the continental slope or approximately the 1500-metres' contour. The *Belgica* surface-observations prove that this boundary-line was, in July, sharply defined even between the melting ice-floes; for as soon as the ship, sailing through the ice, came west of the boundary of the Polar Current, *i. e.* approached the continental slope, the salinity sank suddenly below 32·0 ‰.

A part of the Polar water transported by the current is carried eastwards in the sea north of Jan Mayen—probably as a rule in about 72° and 73° N. Lat. (cf. Figs. 93, and 108)—and joins the great cyclonic circulation in the Northern Norwegian Sea (the Greenland Sea). We propose to call this branch the *Jan Mayen Polar Current.*

Unfortunately no stations were ever taken in the sea north of Jan Mayen between this island and AMUNDSEN'S Stations 13—23 (see Pl. XIII). We know consequently very little about this branch of the Polar Current and about the conditions in this part of the sea; but judging from the temperatures observed, it was probably Polar water coming this way, which occurred at MOHN'S Stations 300 (from 18 to 183 metres), 298 (from 55 to 183 metres), and 297 (from 55 to 183 metres) and at RYDER'S Station VIII (from 18 to 165 metres) [cf. NANSEN, 1906, Pl. VIII; see also our Fig. 95]. The positions of these stations may be seen in Pl. XIII (Fig. 1, Stations). The minimum temperature was at Stat. 300, — 1·6° C. in 73 metres, at RYDER'S Stat. VIII — 1·7° C. between 55 and 90 metres, at Stat. 298 — 1·2° in 91 metres, and at Stat. 297 — 0·8° C. between 91 and 128 metres. At all these stations the layer of cold Polar water was resting upon an intermediate layer of warmer water (with temperatures above 0° C.) similar to that underlying the East Greenland Polar Current.

We know very little about the course of the Polar current in the sea between Jan Mayen, Greenland, and Iceland, as very few stations have been taken in this region. The three *Belgica* Stations 48, 49, and 50 (Fig. 94) between Greenland and Jan Mayen (see the soundings of 1130, 1650, and 1525 metres, in Pl. I), are evidently outside the main body of the Polar Current, which runs nearer the edge of the continental shelf.

The isopyknals in a section through these three stations (Fig. 96) have hardly any inclination and they seem to indicate that there has been very little movement in the water, or there has at any rate been very little difference between the velocities of the movement near the surface and in the deeper strata. But during the NATHORST Expedition in 1899, a station (NXI in Pl. XIII) was taken (on July 27th, 1899) on the continental shelf (near the locality of 256 metres in Pl. I) just inside the locality of the *Belgica* Stat. 48. If this station be introduced in the section (see Fig. 96), the isopyknals, and other equilines, exhibit very steep inclinations between that station and Stat. 48 (cf. Pl. XXV, Sect. II), indicating that there is probably a very rapid southward current along the edge of the continental shelf like that which we found farther north.

We may consequently conclude that also in this region the main body of the Polar Current is confined to the edge of the continental shelf and the upper part of the continental slope off the Greenland coast; but the top layer of Polar water extends over the greater part of the sea between Greenland and Jan Mayen (see Fig. 96, and Pl. XXV, Sect. II), being comparatively thin at the *Belgica* Stations 48—50, east of the main body of the current.

The isotherm of 0° C. at these stations was probably at a depth of about 130 or 150 metres. At our Station 19 (Aug. 7th, 1900) it may have been somewhat deeper, and at AMDRUP'S Stat. II, just west of Jan Mayen (June 29th, 1900) the layer of Polar water was still deeper, having a minimum of — 1·7° C. at 60 and 80 metres, and 0° C. at about 215 metres [cf. NANSEN, 1906, Pl. IX]. There may have been a northward movement of the water at the two last-named stations, west of Jan Mayen, which has pressed the surface water against the coast (on the right hand side of the movement) by the deflective force due to the Earth's rotation; and in this manner the surface-layer of Polar water may have become deeper near the island.

The observations are much too few (and taken in different years) to give any certain information about the movements of the water in this region, but we think that there may be some kind of cyclonic vortex-movements in the Iceland Sea between Greenland, Jan Mayen, and Iceland, by which the Polar water is spread out over the whole area. But we shall not attempt to go into the details of this movement.

Our numerous observations at the several Stations 19—24 (Aug. 7, 1900), just south-west of Jan Mayen (see Pl. III), and also at Stations 25 and 29 east of Jan Mayen, prove that the movements of the waters in the sea near this island must be very complex; the water of the Polar Current meets with the warmer water of the great cyclonic vortex-movement of the southern Norwegian Sea, and very heterogeneous mixtures of warm and cold waters result therefrom. At stations only a few miles apart, the conditions were entirely different, *e. g.* at Stat. 20 nothing but positive temperatures were observed between 0 and 300 metres, while at the stations on both sides and only some few miles distant, the typical temperatures of the Polar water were observed. We consider it possible that there is, to some extent, an anticyclonic movement round the Jan Mayen Bank (cf. Figs. 93, Surface; and 108).

As to the course of the Polar Current along the Greenland coast, between the above-mentioned region and Denmark Strait, we know hardly anything. Two stations with vertical series of temperatures were taken by RYDER in August, 1892, in this region, Stat. XXVI in 69° 18′ N. Lat., and 23° 37′ W. Long., and Stat. XXVII in 69° 36′ N. Lat., and 19° 43′ W. Long. Both were on the continental shelf, the first close to land in 175 metres of water, and the second, with a depth of 329 metres (see Pl. I), probably near the edge of the shelf. Both series give the vertical distribution of temperature that is typical for the Polar water, but the temperatures are comparatively high, especially in the series near land, the minimum at about 90 metres being only —1·4° C. This may, at that place, be due to the admixture of Greenland coast water, which has for instance raised the temperature to 0·4° C. at 9 metres, while at 18 metres it is —0·8° C.

At Stat. XXVII, the following observations were taken:

Depth in Metres	0	2	9	18	22	28	46	93	140	185	230	280	320
Temperature ° C.	0·8	0·6	0·4	0·1	— 0·1	— 1·0	— 1·7	— 1·2	— 0·6	— 0·1	0·5	0·6	0·6

The isotherm of 0° C. has consequently been at about 190 metres at this station, which is approximately the medium thickness of the Polar water in the North Polar Basin, or somewhat less than its thickness at the stations with similar depths, near the edge of the shelf, given in the table on pp. 274—275.

It seems probable that the Polar Current is checked in its southward course along the Greenland continental shelf by the Iceland-Greenland Submarine Ridge and by the Irminger Current trying to run northwards over the same ridge. The case is similar to that of the Atlantic current being checked in its north-eastward course by the Wyville Thomson Ridge and the Færoe-Iceland Ridge over which it meets the East Iceland Arctic Current. A sea-current running along a continental slope over deeper water, meets with more resistance near a submarine ridge, and as only a part of the water-masses carried by the current can pass across the ridge, the rest of the water must broaden out and be deflected towards the left along the ridge, as is the case with the Atlantic Current (see above, Fig. 39). This is also the case with the East Greenland Polar Current. Only a part of it can cross the Iceland Greenland Ridge near the Greenland side, the rest of the water-masses conveyed by the current are deflected eastwards and form to some extent a cyclonic vortex-movement in the Iceland Sea (between Iceland, Jan Mayen, and Greenland, see above p. 285), while a great volume of Arctic water runs towards the south-east along the continental slope off the north-east coast of Iceland (see Fig. 39, and Pl. XIII), where they form the East Iceland Arctic Current, just as the Atlantic Current forms the westward current along the south coast of Iceland, and the Irminger Current, the greater part of which is deflected westwards along the Iceland Greenland Ridge, and then south-westwards.

4. The East Iceland Arctic Current.

The usual designation Polar for this Current is misleading, as it is only to a limited extent composed of Polar water. The main body of the current is composed of waters formed by the intermixture of originally Atlantic water with Polar and Arctic water and with Iceland coast water.

What we call *Arctic water* is formed in the Norwegian Sea (Greenland Sea and Iceland Sea), and is an intermixture of originally Atlantic water with originally Polar water, and also with water which has been cooled during the winter in the Norwegian Sea, and which, during the summer, may have been diluted by the water of the melting ice. Arctic water forms more or less the central waters, and we find Arctic water in the eastern boundary-areas of the East Greenland Polar Current; it is also a similar kind of water which forms the intermediate warmer layer underlying this current. The Arctic water has temperatures between $0°$ and $2°$ C. and salinities from 34·6 to 34·9 ‰.

Most of the originally Atlantic water forming the Iceland Current is carried into the Norwegian Sea by the Norwegian Atlantic Current, but a smaller amount of Atlantic water also comes from the small branch of the Irminger Current running north-eastwards across the Iceland-Greenland Ridge (cf. Pl. XIV B, Fig. 2, at Stat. 14), and following the north coast of Iceland. It is evidently water from this current which is seen in the Danish section, Fig. 97, north of Iceland (see Fig. 94), at Stat. 75, having salinities above 34·9 ‰ and even above 35·0 ‰. It is obviously exactly the same kind of water which is seen at our Stat. 14 of Aug. 4, 1900 (Pl. XIV B, Fig. 2). Remnants of this same kind of Atlantic water are probably seen in Section V, Fig. 99, taken seawards from the north-east coast of Iceland. The

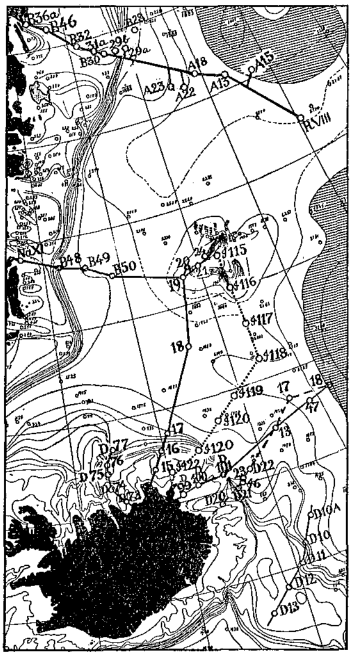

Fig. 94. Chart showing Lines of Sections in Figs. 95—102. Scale 1 : 18,000,000.

salinity is here still above 34·9 ‰ at the Stations Da. 99, Da. 100, and Da. 101 [cf. J. N. Nielsen, 1905]. In our Section IV (Fig. 98), from Iceland to Jan Mayen of August, 1900 (Pl. XIV B, Fig. 1), there is no indication of this Atlantic water; but the reason may possibly be that the distance between Stations 15 and 17 is too great, and if there had been stations in between, water of this kind would possibly have been found.

The sections in Figs. 95—100 and the charts in Pl. XIII give a clear representation of the connection between the East Greenland Polar Current and the East Iceland Arctic Current, and demonstrate the origin of the waters of the latter current. The chart, Fig. 94, shows the positions of the sections.

The sections had to some extent to be constructed by means of observations taken in different years (1900, 1903, 1904, 1905, and one Station in 1899), chiefly in the month of *August*. Some few Stations (Da. 73—Da. 77, Fig. 97 and Na. XI, Fig. 96) were taken in the latter part of the month of July, and a few (our Stats. 46, 13, 47, 18) in the first few days of September. The sections cannot therefore on the whole be considered as trustworthy representations of the conditions in any special year, but it may be assumed that they represent approximately the main general features of the distribution of temperature, salinity, and density in the month of August. The charts, in Pl. XIII, were constructed in a similar manner, by using observations from different years, and trying to give the equilines shapes that should represent approximately the average conditions in the several years, without any pretence to accuracy. The *Belgica* observations (in Figs. 95, 96) and the Danish observations (in Figs. 97, 99, 101) were not known when these charts were constructed. If they could have been introduced they would have somewhat altered the shape of the equilines in the charts.

We have pointed out above that the southward movement of the East Greenland Polar Current is chiefly limited to the continental slope, while there is very little movement over the continental shelf, and that the layer of Polar water extending seawards from the con-

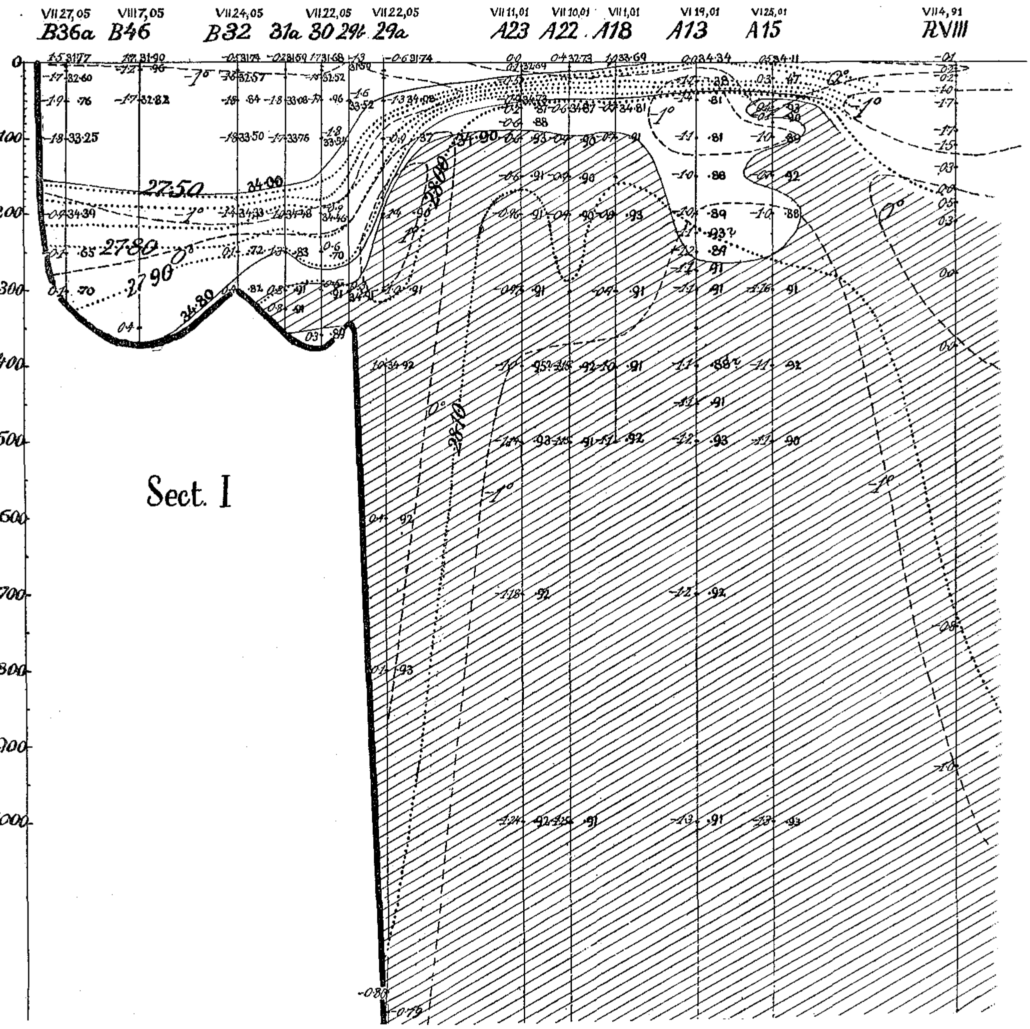

Fig. 95. Section through the *Belgica* Stats. 36 a—29 a, and AMUNDSEN'S Stats. 23—15, to RYDER'S Stat. VIII. Horizontal Scale 1 : 6,000,000; Vertical Scale 1 : 10,000. Single hatching indicates salinity between 34·90 and 35·00 ‰.

tinental slope *e. g.* between Greenland and Jan Mayen evidently also moves very slowly and probably forms vortex-movements (cf. p. 285). In the East Iceland Arctic Current the conditions are altogether similar, the chief movement being limited to the slope on the right side of the current (*i. e.* off Iceland and the Færoe-Iceland Ridge).

Fig. 98 (see also Pl. XIV B, Fig. 1) is a section between Iceland and Jan Mayen through stations taken during our cruise in August, 1900 (cf. Pl. III). There is a

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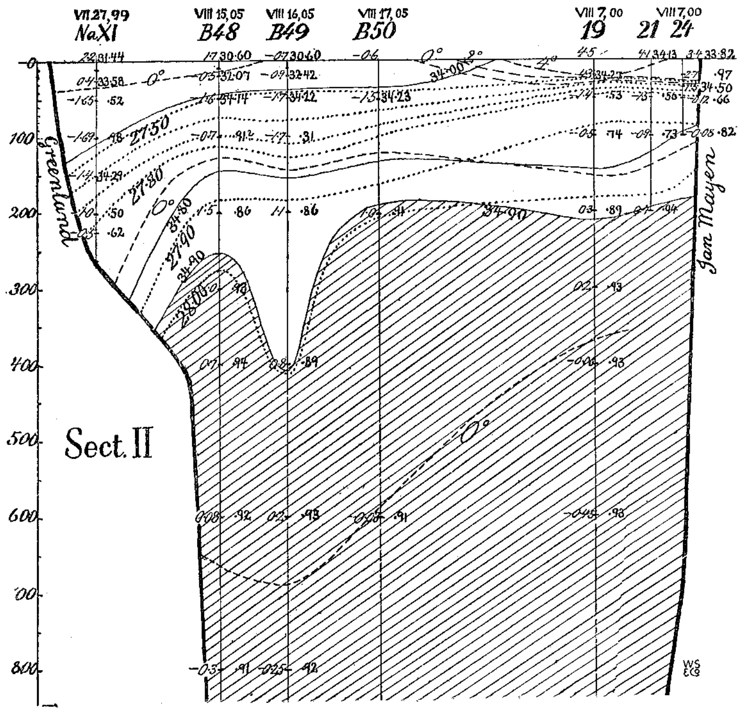

Fig. 96. Sections from Greenland to Jan Mayen through NATHORST'S Stat. XI, the *Belgica* Stats. 48—50, and the *Michael Sars* Stats. 19—24 (Scales and hatching same as in Fig. 95).

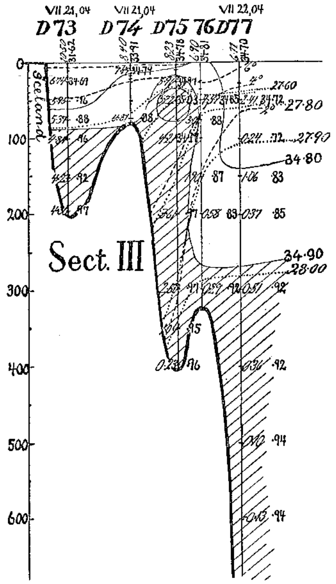

Fig. 97. Section through the Danish Stats. 73—77, north of Iceland (Scales and hatching same as in Fig. 95).

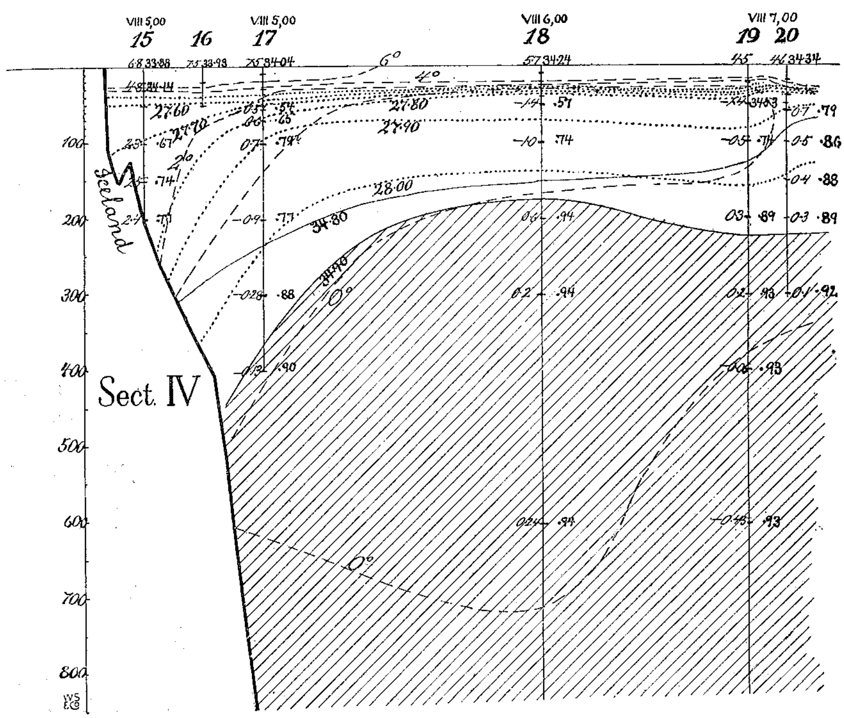

Fig. 98. Section from Iceland to Jan Mayen through our Stats. 15—20 (Scales and hatching same as in Fig. 95).

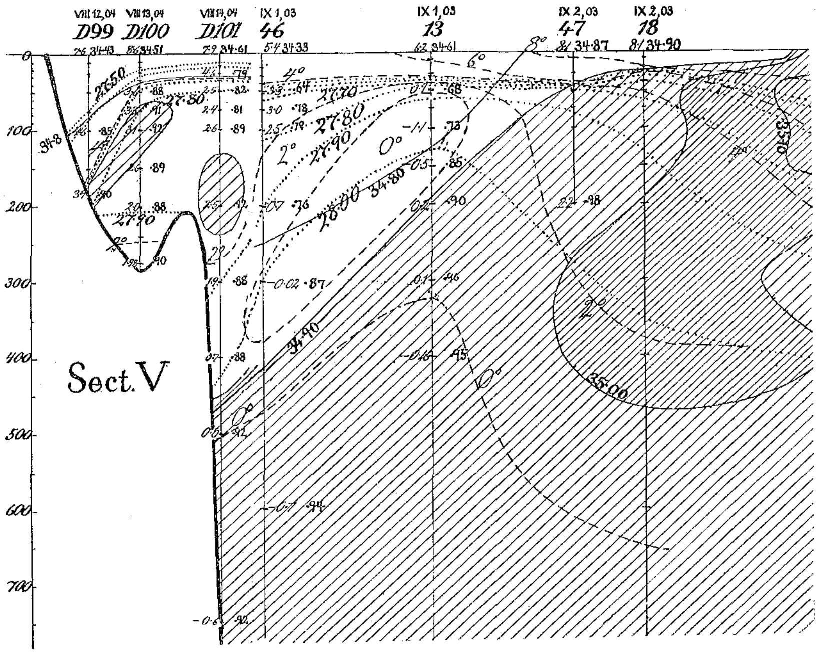

Fig. 99. Section north-eastwards from Iceland (cf. Fig. 94, unbroken line) through Danish Stats. 99—101 (of August, 1904) and the *Michael Sars* Stats. 46—18 (of September, 1903) (Scales same as in Fig. 95.

striking resemblance between this section and the section between Greenland and Jan Mayen (Fig. 96). The sea is covered by a similar top layer of cold water with salinities below 34·9 ‰. But the temperatures, especially near the surface, and near Iceland, are considerably higher than in the Section II through the *Belgica* Stations (Fig. 96) and so are the surface-salinities. It is evidently to some extent the same top layer; but a great deal of the cold surface layer of Polar water with low salinities in Section II, Fig. 96, follows the Greenland continental slope into the Iceland-Greenland Channel, and does not run out through our section between Iceland and Jan Mayen. The surface-layer in the latter section has been heated directly by the sun, and also by intermixture with warmer and salter water, which has increased the salinity as well. Near Iceland there is evidently also a considerable admixture of comparatively warm Iceland coast-water.(1)

The thickness of the Arctic or Polar top layer in our section (Fig. 98) is about 200 metres north of Stat. 18; but near Iceland it increases to about 400 metres. Its temperature in the northern part is chiefly below 0 ° C., and shows the vertical distribution which is typical for the Polar water. Only near the surface there is a layer about 25 or 30 metres thick with temperatures above 0 ° C.(2) At Stations

(1) As mentioned above it is very probable that near the Iceland slope between Stats. 15 and 17 there has been a volume of warm water, with comparatively high salinities, coming from the Irminger Current (cf. Figs. 97, 99).

(2) Stat. 20 is a remarkable exception, having only positive temperatures, as was mentioned above.

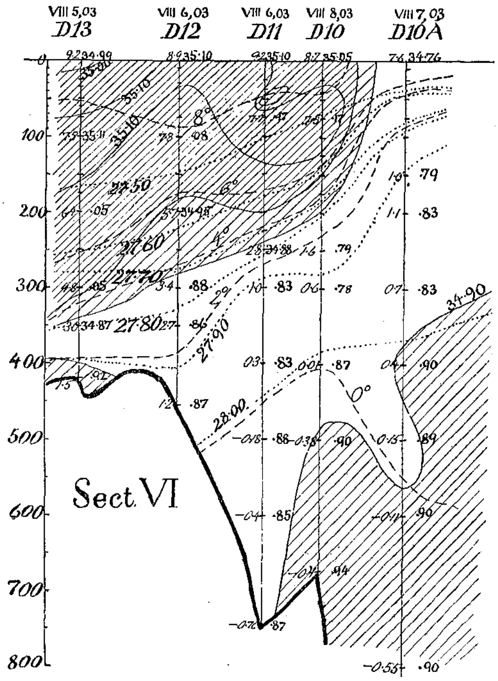

Fig. 100. Section across Færoe-Iceland Ridge, through Danish Stats. 13—10 A. (Scales same as in Fig. 95.)

15—17 near Iceland this is entirely different, as the warm top layer is much thicker, at Stat. 17 about 150 metres, and near the edge of the continental shelf probably more than 250 metres. The cold water is therefore depressed at these stations, by this overlying warm layer, to levels between 150 and more than 400 metres at Stat. 17, and on the continental slope even deeper.(1) The increase of the warm top layer near Iceland is evidently to some extent due to the Iceland coast-water, which has raised the temperatures and decreased the salinities, but it is also due to the rapid eastward movement of the surface layers, which presses them towards the right, and makes them accumulate against the continental shelf, on the right hand side of the current.

The horizontal course of the isopyknals between Stat. 17 and Stat. 20 (off Jan Mayen) in our section, prove that the surface layers cannot have been moving much in relation to the underlying strata, unless the movement has had exactly the same direction as the section and no appreciable components at right angles to it. There is, however, no probability of any rapid movements along this direction, either from Jan Mayen to Iceland or in the opposite direction.

We may consequently conclude that the cold surface layer of Arctic or Polar water between Iceland and Jan Mayen, as also between Greenland and Jan Mayen, moves only very slowly in by far the greater part of this sea-area. For lack of observations we can say nothing about the details of these slow movements; but we consider it probable that there may be a cyclonic vortex-movement (cf. Fig. 108) with many smaller vortices in this great area.

The charts for 50 and 100 metres in Pl. XIII, demonstrate how this water with comparatively low temperatures and salinities extend

(1) The isotherm of 0° C. in Pl. XIV B, Fig. 1 ought probably at Stat. 17 to have a shape more like Fig. 98, for the cold top layer with temperatures below 0° C. is probably separated from the cold bottom-water by a warmer intermediate layer with temperatures above 0° C.

south-eastwards into the southern Norwegian Sea; but it moves very slowly in the greater part of the area which it covers in this region, and, as will be mentioned presently, is here to some extent near the central part of a cyclonic movement (cf. Fig. 99, Stat. 13).

It is only along a narrow band near the continental slope that there is more movement in these top layers of Arctic water and Iceland coast water.

The steep inclination of the isopyknals (especially of 27·70—27·90) between Stats. 17 and 15 (Fig. 98) proves that there must have been a rapid movement of the surface layers in a south-easterly direction (in relation to the underlying water) along the continental slope, and the main body of the East Iceland Current evidently passes through this part of the section. This is in perfect accordance with the results we arrived at farther to the south-east, where we found the greatest velocities of the current along a narrow band over the northern slope of the Færoe-Iceland Ridge, while farther seawards to the north-east there was evidently very little motion (see above, Fig. 39).

The "Tongue" of Arctic Water along the Slope of the Færoe-Iceland Ridge.

This tongue of water with salinity between 34·86 and 34·90 ‰ and low temperature is a remarkable feature in the circulation of the Norwegian Sea which is seen in all sections across the Færoe-Iceland Ridge or across the southern part of the Norwegian Sea at all seasons of the year (Pls. XIV A—XXIV B) and in all our charts for depths down to 300 and 400 metres. We observed this water for the first time at intermediate depths in our section from Norway to Iceland in July 1900 (Pl. XIV A, Fig. 1) and by means of the later Norwegian and Danish researches we can now trace the course of this water from the continental slope off the east coast of Iceland along the slope of the Færoe-Iceland Ridge and off the Færoes, past the Færoe-Shetland Channel and thence towards the north-east and north, or even north-west. Many observations in the region of this tongue were taken especially in May, 1903 and 1904, and the charts in Pls. IX and XII (and also Pl. XIII), demonstrate the course of this tongue very clearly. It is evident that it follows the cyclonic movement of the southern Norwegian Sea, and the last traces of its water disappears near the central area of this cyclone, evidently on account of intermixture with the surrounding waters.

A study of these charts in connection with those of other years and seasons will give much information about the extent and variations of this tongue. The chart for 200 metres of May—June, 1903 (Pl. IX), shows that it may sometimes extend so far towards the north-east as off Helgeland (cf. the sections, Pl. XXI A, Figs. 2 and 3). It is remarkable how this tongue retains its peculiar shape along the route from between Iceland and the Færoes to the sections seawards from the Sognefjord (May 1901, February 1903, May 1903, August 1903, November 1903, May 1904), and seawards from Stad (May 1903 and 1904) and even seawards from Helgeland (May 1903).

The sections Figs. 96—100 give an idea of the origin of the water of this tongue. It evidently comes from the deeper layers of the East Iceland Arctic Current, and is Arctic water, of the kind which occurs near the continental slope of Iceland, in Figs. 98, 99. It is however strange that hardly any trace of this water, with temperature between 0° and 2° C., is seen in the May section, Fig. 191. This Arctic water is also very similar to that which forms the intermediate warm layer, with temperatures of 1·1 and 1·5° C. and salinity of 34·86 ‰, underlying the cold Polar water at the *Belgica* Stats. 48 and 49 (Fig. 96). We consider it probable that such Arctic water with the right density will always be formed by gradual intermixture in the sea between Iceland, Greenland, and Jan Mayen, and to some extent also by the vertical convection current created by the cooling of the surface during the winter.

Our section Fig. 1, Pl. XIV B, proves that it is a comparatively small part of the water carried by the East Iceland Arctic Current, between Stats. 15 and 17, that is what we might call Polar water. At Stat. 17 it occurs only in the deeper strata (below 150 metres), and has comparatively high salinities and not very low temperatures, proving that even this water has been much intermixed with warmer and more saline waters. In the sections across the Færoe-Iceland Ridge, to the south-east, there is even still less of this cold Polar water (cf. Pl. XIX, Fig. 5; Pls. XXI B, XXII, XXIV B). Farther seawards (*e. g.* at Stats. 12—15, May 1901; Stats. 12—16, May 1902; Stats. 13—16, May 1903; Stat. 13, Aug. 1903; Stats. 65, 66, 15—17A, May 1904) there is more of it, even with temperatures below — 1° C., but, as will be mentioned presently, it has evidently very little motion and is renewed only very slowly.

Our sections (Pls. XX *et seq.*) seem to indicate that the "tongue" has often a higher temperature in the sections off the Norwegian coast than near the Færoe-Iceland Ridge. The water forming the tongue is probably heated on its way from Iceland towards the south-east.

This is easily seen by noting the course of the isotherm of 2° C. in the sections. In most sections across the Færoe-Iceland Ridge (Pls. XXI B, XXII, XXIV B) the isotherm of 2° C. runs near the upper boundary of the tongue, *i. e.* the greater part of its water has a temperature much below 2° C. or even below 1° C. In the sections near Iceland (Pls. XIX, Fig. 5; XXI B, Fig. 7; XXII, Fig. 6; XXIV B, Fig. 7; see also Figs. 99 and 100), the isotherm of 2° C. is quite close to the isohaline of 34·9 ‰, or even above this curve. But in most sections to the south-east the isotherm of 2° C. is deeper below the isohaline of 34·9 ‰, especially in August, 1903, when the greater part of the tongue north of the Færoes had temperatures above 2° C. (Pl. XXII, Fig. 4); but even in May, 1904, the isotherm of 2° C. was in this locality running near the middle of the tongue (Pl. XXIV B). The fact that the tongue is warmer in the August(1) sections than in the May sections proves that the changes in the temperature of the tongue is chiefly due to the heating from above, during its course south-eastwards, and this heating from above is especially appreciable during the summer.

In many of our sections seawards from the Norwegian coast the temperature of the tongue is still higher than north of the Færoes, and the isotherm of 2° C. very often runs along the middle of the tongue, see the *Sognefjord section* in February, 1903 (Pl. XX, Fig. 1), in May, 1903 (Pl. XXI A, Fig. 1), in August, 1903 (Pl. XXII, Fig. 1), and in May, 1904 (Pl. XXIVA, Fig. 1). In the *Stad* and *Helgeland sections* of June 1903 (Pl. XXI A) the tongue has become still more heated, and it lies above the isotherm of 2° C. having temperatures about 2·5° C., but the tongue does not in these sections descend deeper than 300 and 250 metres, its deeper part having evidently been intermixed with the surrounding water, so that the salinity has been increased above 34·90 ‰. In the *Stad section* of June, 1904, the isotherm of 2° C. passes through the tongue (Pl. XXIV A, Fig. 2); but in the deepest part of it, at Stat. N 70, there is even a temperature of 3·13° C. The increase of the temperature of the tongue towards the east is also distinctly seen in our charts for different depths, especially for May, 1903, see also the isotherm of 1° C. and 2° C. in the charts for May, 1904.

The *Sognefjord section* of November, 1903, is a strange exception, as the tongue was then below the isotherm of 2° C. (see Pl. XXIII, Fig. 1; see also the charts in Pl. XI) and had temperatures between 1·86 and 1·99° C. which is colder than in any other season when observations were taken along this section, except in May, 1901, when the Atlantic water of the Sognefjord sections was also unusually cold (cf. above pp. 177, 185, 191).

The movements in the tongue were already mentioned several times above (cf. p. 135 *et seq.*). The inclinations of the isopyknals in our sections indicate that it moves south-eastwards with the greatest surface-velocities near the slope of the Færoe-Iceland Ridge; as will be mentioned later the velocities seem to be considerably greater in the autumn than in the spring. The shape of the isopyknals in our

(1) See also the section northwards from the Færoes in August, 1904, *Bull. des Result. acq. pend. Aout 1904*, Part B, Pl. V.

sections indicate, moreover, that at some distance from the Færoe Iceland Ridge there is very little motion in the water. For instance at Stats. 13 and 47 in Fig. 99 and at Stats. 13 and 17 in Fig. 101 there has evidently been very little motion, while on the other side of these stations, at Stat. 18, there may have been a movement in the opposite direction (cf. Fig. 39). All our sections across the Færoe-Iceland Ridge indicate similar conditions, and it seems as if there is hardly any movement in the cold water along an axis through Stat. 13 (of May and August, 1903) and towards the south-east, almost parallel to the Færoe-Iceland Ridge. Along this axis the water is very heavy, its mean density in May being above 27·90 between 0 and 300 metres, and above 28·00 between 0 and 600 metres, as is demonstrated by the two charts of mean densities for May, 1904, in Pl. XII (see also the similar charts for July—Sept., 1900, Pl. III, May and August, 1903, Pls. IX, X). The renewal of the cold water of this axis must be very slow. It is probable that on its south-west side the movement goes in a south-easterly direction, and fairly rapidly as the isopyknals lie there close together in our charts (cf. p. 159) while on the north-east side of it, where the distances between the isopyknals are much greater, there is a slow movement in some northerly direction.

The Seasonal Variations in the East Iceland Arctic Current.

For lack of observations only very little can be said about the seasonal variations in the East Iceland Arctic Current, and still less about its annual variations. In May and August, 1903, Danish as well as Norwegian observations were taken in the sea east of Iceland which make it possible to construct sections across the East Iceland Current, and these sections may give us some indications of the seasonal changes.

A priori it is to be expected that in the *autumn* the current north-east of Iceland should carry a *maximum* quantity of diluted Arctic water (and coast water) with a maximum average temperature, owing to the combined effect of the melting of the Arctic and Polar ice-masses, during the summer, the increase of the Iceland and Greenland coast water, and the heating by the sun. On the other hand it is to be expected that in the *spring* there should be a *minimum* in the quantity of diluted water (with salinity below 34·9 ‰) carried by the current, and also a minimum average temperature, owing to the formation of ice during the winter and the cooling of the sea-surface. The observations at our disposal prove that such is the case.

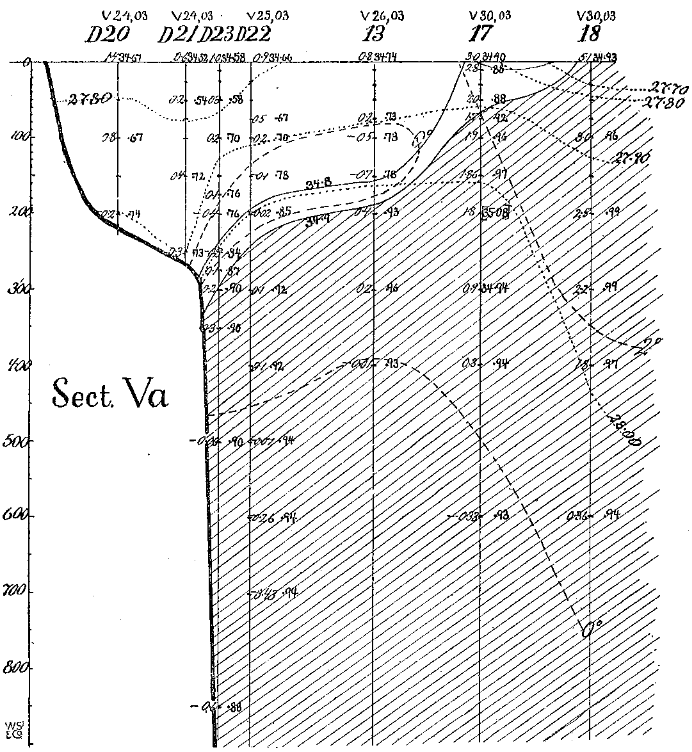

Fig. 101. Section north-eastwards from Iceland (see broken line Fig. 94) through the Danish Stats. 20—22 and the *Michael Sars* Stats. 13—18, May, 1903 (Scales and hatching same as in Fig. 95).

Figs. 99 and 101 represent sections taken very nearly along the same lines north-east from Iceland. The Danish and Norwegian stations of Fig. 101 were taken in the end of May, 1903, the Norwegian Stats. 46, 13, 47, and 18 of Fig. 99 were taken in the first days of September, 1903, while the Danish Stats. 99—101, near land, were taken in August, 1904. These two sections show a striking difference. While in September and August the water-layer with salinities below 34·90 ‰, and densities below 28·00, had a depth of about 400 or 450 metres at our Stat. 46 and Stat. Da. 101, it had in May a depth of no more than 300 metres on the continental slope, between Stats. Da. 21 and Da. 23. At Stat. 13 the depth of the water-layer was very nearly the same in the two seasons, and at Stat. 18, there was only a very thin surface-layer of it in September, but nothing in May. It appears thus to have had a somewhat wider extension on the surface in the autumn than in the spring, but its great variations has chiefly been limited to the very narrow main body of the current, running close along the continental slope of Iceland.

The conditions in May, 1901 and 1902, at our Stations 12 and 13, off the east coast of Iceland (see Pls. V and VI), might seem not to agree with the above results, as the isohaline of 34·90 ‰ was, in May, 1901, below 350 metres at Stat. 12 (see Pl. XVI, Fig. 2) and in May, 1902, at about 350 metres at Stat. 13 (Pl. XVII, Fig. 1). The isotherm of 0° C. of the upper cold layer, was, however, not so deep, in May, 1902, even above the level of 200 metres, or very nearly at the same level as it was at Stat. 13 in May, 1903. The isopyknal of 28·00 was in May, 1901, at about 200 metres at Stats. 12 and 13, but in May, 1902, it may have been somewhat deeper at Stat. 13, On the one hand it has to be considered that there might be slight, more or less, accidental variations in the salinity of the different waters from one year to another, and we see that the variations here are very small only 34·88 ‰ (or 34·86 ‰) instead of 34·91 ‰. On the other hand, as we have mentioned in Chap. VI, there might be great temporary disturbances, boundary waves, vortex-movements etc. which often alter the level of the boundaries between the layers.

As regards the temperatures of the water of the Iceland current the two sections Figs. 101 and 99, of May and August, show striking differences. At Stats. Da. 20—Da. 22 all temperatures were very low, and the cooling during the winter had by vertical convection currents made the water practically homogeneous over the Iceland continental shelf, with nearly uniform temperature and salinity at all depths, which is best seen at Stat. Da. 20, near land. And at the time of the observations, May 24th and 25th, only a slight heating on the surface is noted in the surface temperature. In the surface layers at Stat. Da. 22, and our Stat. 13 there have also been active convection currents during the winter creating nearly homogeneous water down to 100 and 150 metres. There are consequently comparatively few isopyknals in this section, and they have no very steep inclinations. This seems to indicate that the current has been moving with very small velocities.

In the autumn it is quite different: the water near the land has become much heated down to considerable depths, the salinities near the surface has become lower, the surface layers are considerably lighter, and there are many more isopyknals with steeper inclinations, indicating that the surface velocity of the current has been much increased, which is evidently also the reason why the layer with salinities below 34·9 ‰ has become so much deeper on the continental slope; the increased surface velocity has pressed it down on the right side of the current, on account of the deflective force due to the Earth's rotation.

In the section farther south through the Danish stations 19, 18, 17 and 10, there are quite similar differences between May and August, 1903, see Pl. XXI A, Fig. 1, and Pl. XXII, Fig. 1. At Stat. Da. 10 the isohaline of 34·90 ‰ was at about 300 metres in May, and at about 500 metres in August, provided that the determinations of the salinity are quite correct; but this may be a little doubtful as there is much less difference in the temperatures at these depths, the isotherm of 0° C. being at about 400 metres at Stat. Da. 10, both in May and August.(1) The temperatures of the top layer, with salinities below 34·9 ‰, are in May very low and there is only little difference vertically, both in temperature and salinity. The water over the continental shelf is nearly perfectly homogeneous, especially at Stats Da. 19 and Da. 18, but also at Da. 17 and Da. 10. There are consequently comparatively few isopyknals in the section, and the movements seem to have been slow. In August the temperatures of the upper strata have been much raised, and the salinities have been lowered. There are consequently many more isopyknals, and their inclinations indicate much more rapid movements in the upper strata.

In the section through the Stats. Da. 13 to Da. 10 A (Fig. 100) farther to the south-east (see Fig. 94) there are quite similar differences between May and August, 1903 (cf. Pl. XXI B, Fig. 6, Pl. XII, Fig. 5) indicating a greater volume of the tongue of the Arctic water with many more isopyknals and greater surface velocities in August than in May 1903.

And if this section of August, 1903, be compared with the same section of May, 1904 (Pl. XXIV B, Fig. 6), there is a similar difference, although the volume of the "tongue" in the "bight" was larger that spring than in May, 1903, provided that the determinations of salinity be correct.

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(1) It will be mentioned in Chap. XI (p. 322) that the isotherm of 0° C. ought probably to be drawn somewhat differently in both figures (Pl. XXI A, Fig. 1, Pl. XXII, Fig. 1) as it should certainly not rise from 400 metres at Stat. Da. 10 to about 200 metres at Stat. Da. 17; but should pass to the continental slope probably below 400 metres. The cold water near the bottom at Stat. Da. 17 is Polar water with lower salinity, while the cold water below 400 metres at Stat. Da. 10 is bottom-water.

To judge from the observations taken at the same Danish stations in August, 1904 [cf. *Bull. d. Res. acq.* etc. Aout 1904, p. 24], it seems, however, to have been a comparatively small volume of Arctic water with salinity below 34·9 ‰ in the "bight" that autumn, as it was not observed at Stats. Da. 13 and Da. 12, and only at one depth (350 metres) at Stat. Da. 11; at Stat. Da. 10 it occurred at 150 and 200 metres and between 50 metres and the surface. It may, therefore, be doubtful whether there actually is a seasonal variation (between May and August), as indicated above, in the volume of the Arctic water in the "tongue" along the northern slope of the Færoe-Iceland Ridge. It may be that the effects of the increase during the summer of the volume of this water north and north-east of Iceland does not reach the Færoe-Iceland Ridge before later in the winter. We cannot, therefore, expect to find any distinct indications of such variations in the sections across the ridge farther to the south-east, and north of the Færoes (see Pls. XXI B, XXII, XXIV B). But they all show similar differences between May and August as regards the number of isopyknals, indicating greater surface-velocities along the continental slope in the autumn.

Annual Variations in the East Iceland Arctic Current.

No certain conclusions as to the *annual variations in the East Iceland Arctic Current* can be deduced from the Danish observation-material of a few years only. As was mentioned above (p. 185) our sections seawards from the Sognefjord taken in May, 1901—1905, seem to indicate that the "tongue" of Arctic water was in

May, 1901, very great and cold.	*May, 1902,* no tongue observed.	*June & July, 1902,* no tongue observed.	*May, 1903,* divided in two parts.	*August, 1903,* small.
November, 1903, fairly great and cold.	*May, 1904,* great but not cold as in 1901.	*May 1905,* no tongue observed.		

These observations agree fairly well with the Danish observations along the Færoe-Iceland Ridge and east of Iceland in the few years from which there are observations. As was mentioned on p. 185 the Danish observations seem to indicate that north of the Færoes the tongue of Arctic water was smaller in May, 1903, than in May, 1904; but in May, 1905, it was very small. This also agrees with the facts represented in Fig. 99, which proves that the surface-layers with comparatively low salinities were deeper at our Stat. 46, of Sept. 1, 1903, than at Stat. Da. 101, of Aug. 14, 1904. The more southern position of Stat. 46 as compared with Stat. Da. 101 (cf. Fig. 94) is not sufficient to account for this difference. It may seem probable that the

Arctic water being east of Iceland in the autumn of 1903 and 1904 has reached the sea north of the Færoes in the spring of 1904 and 1905. The observations in the "bight" also indicate that there was much less Arctic water in the "bight" in August, 1904, than in August, 1903 (see above p. 300), and this may account for the small amount of Arctic water in the Sognefjord section of May, 1905.

If what we have said above be correct, it would agree very well with the variations in the mean temperature of the Atlantic water in the southern Norwegian Sea (cf. p. 185); the observations of May, 1905, being the only exception, as there was very little Arctic water in the Sognefjord section while the mean temperature was low. On the other hand the volume of the Atlantic water was great in May, 1905, and we have also mentioned that the biological conditions do not seem to have been favourable in the southern Norwegian Sea and the North Sea in the season preceding the spring of 1905, as was proved by the spawning of the *herring* (cf. p. 210). But in the winter before May, 1904, the biological conditions seem to have been very good, as was proved by the great quantity of haddock and herring born that year. This coincides with the great tongue of Arctic water in the Sognefjord section of May, 1904, and the unusually low temperature in the tongue in the preceding November (cf. above p. 295) which in our observation-material was only equalled by the very low temperatures in May, 1901, in which year the biological conditions seem to have been even more favourable as is proved by the spawning of the haddock (cf. p. 208).

The observations thus agree with our assumption that the variations in the volume of Arctic water carried by the Iceland Current are of some importance for the biological conditions in the southern Norwegian Sea and in the North Sea. But the observations are much too few and too accidental and from a much too small number of years to prove anything; and no certain conclusions can be drawn in this respect at present.

The only observations in the East Iceland Current which might be expected to give some information about the conditions in earlier years, are the observations taken during the Danish *Ingolf* Expedition in 1896. Fig. 102 represents a section from Iceland to Jan Mayen

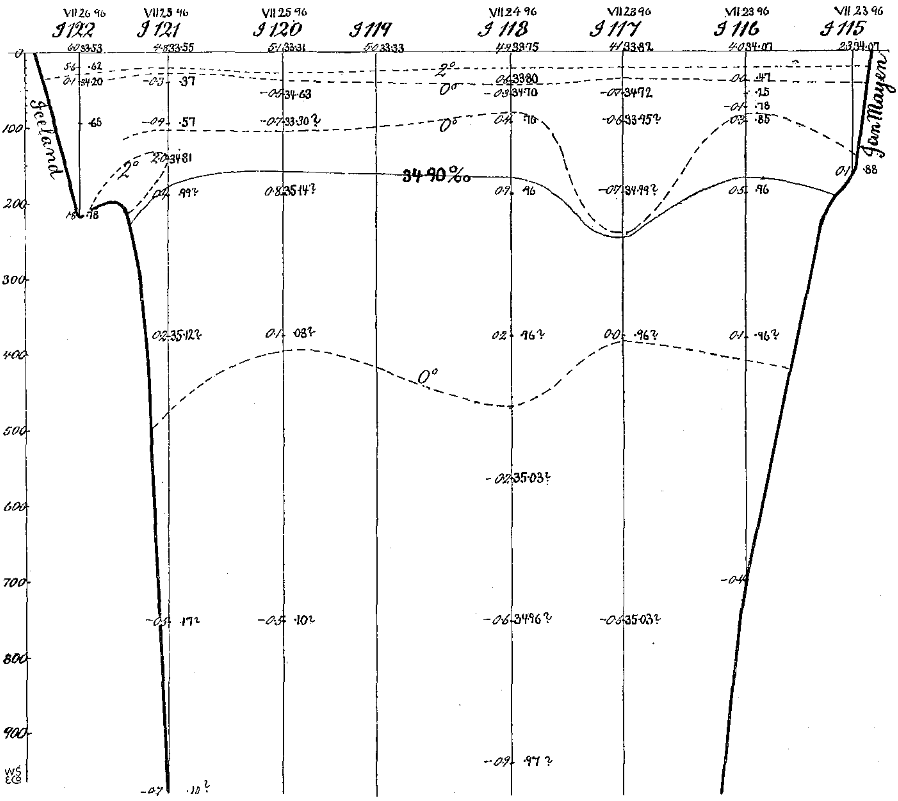

Fig. 102. Section from Iceland to Jan Mayen, through the *Ingolf* Stats. 122—115, July, 1896. (Scales same as in Fig. 95.)

through the *Ingolf* Stats. 122—115, of July, 1896. It passes along a curved line (cf. the dotted line in Fig. 94) between our Section IV (Fig. 98) and Section V (Fig. 99). The values of salinity of the Ingolf section are too inaccurate to be comparable with the modern observations. Although the observations have been computed by Knudsen's Tables, they give salinities of 35·10, or even 35·17 ‰, for the bottom-water with temperatures of —0·5 ° C. or lower (cf. Stat. *I* 121). It is, however, probable that the temperatures are trustworthy. But the difference between the isotherms of this section of July, 1896, and our Section IV of August, 1900, as well as Section V of 1903 and 1904, is nevertheless striking; and cannot be accounted for by the different positions of the sections, for there is in several respects more resemblance between Sections IV and V. The difference is especially remarkable at the stations near Iceland. The isotherms of 0 ° C. and 2 ° C. at the *Ingolf* Stats. 122 and 121 prove that there has been much less Arctic water with low salinities off the north-east coast of Iceland in July, 1896, than there was in August, 1900, in September, 1903, and in August, 1904. At the same time the surface-temperatures and the temperature of the upper water-strata were much lower in the end of July, 1896, than in the beginning of August, 1900, &c. If this be correct it might seem to indicate the possibility of great variations in the waters of the East Iceland Arctic Current.

5. The Denmark Strait Polar Current.

The quantities of Polar ice continually carried southwards through Denmark Strait, often extending almost to Iceland, prove that a branch of the East Greenland Polar Current runs through this strait, across the Iceland-Greenland Ridge, and southwards along the Greenland coast. This branch of the Polar Current is of special interest as (in connection with the current through Lancaster Sound, &c.) it forms the main outflow from the Norwegian Sea which has to a great extent to equal the inflow of Atlantic water through the Færoe-Shetland Channel, crossing the ridge between Greenland and Scotland at its other end (cf. p. 147 *et seq.*). There are also other outflows, *e. g.* across the Færoe-Iceland Ridge, in the "bight" (cf. p. 137), and through the straits between Greenland and America (cf. p. 147), but the outflow of water through Denmark Strait is evidently of most importance.

Very few observations have, however, been taken in this current, and we have no observation-material on which we can base even an approximate estimation of its volume and characteristics. Our Stat. 13, of August, 1900 (Pl. XIVB, Fig. 2), was just in the outskirts of this current. We found there a layer of typical Polar water between 50 and 250 metres, resting as usual on an intermediate warmer water-layer. But as no stations could be taken farther towards the north-west on account of the ice which stopped us at Stat. 13, we cannot say much more about the current in this region. We do not even know whether the Polar water found by us at Stat. 13 belonged to the main body of the current running south-westwards along the edge of the continental shelf of the Greenland coast; but we think that this is probable, and that Stat. 13 was near the middle of the channel about 600 or 700 metres deep, which is the southward continuation of the Iceland-Greenland Channel (cf. Pl. I, and Fig. 8, p. 69). Through this Channel the Polar Current evidently runs south-westwards, pressed close against the Greenland continental slope, which here seems to be at a great distance from the Greenland coast, the continental shelf being very broad; and through the same Channel a narrow branch of the Irminger Current runs north-eastwards along the Iceland continental slope (cf. our Stat. 14, Pl. XIVB, Fig. 2). The conditions are consequently very similar to those of the Færoe-Shetland Channel. Our Stat. 13 was probably just at the edge of the Polar Current on the Greenland side of the Channel.

The probability is that the movement of the Polar Current is chiefly limited to a narrow belt over the continental slope, along the edge of the continental shelf—in the same manner as was proved by the *Belgica* observations off the northern east coast of Greenland (cf. p. 269 *et. seq.*)—while there is comparatively little movement in the Polar waters covering the continental shelf, inside its edge west and north-west of our Stat. 13. This gives a natural explanation why there is, as a rule, so much ice off the Greenland coast just in this region, and why the margin of the ice is so very often met with just in the region of our Stat. 13, or near the edge of the Greenland continental shelf.

Our assumption agrees well with the experiences of the sealers, who catch the bladder-nose seal or hood seal (*Cystophora cristata*) in Denmark Strait, generally in June and July. It is a common experience that the current sets hard towards the south-west (or west as the sealers say) along the edge of the ice, and that one always has to keep well towards the north-east in order not to be carried too far towards the south-west. But as soon as the vessels penetrate some distance into the ice, the drift towards the south-west seems to be considerably less.

In June and July, 1882, Nansen [1884] was enclosed in this ice for twenty-two days (from June 25th to July 17th), and during that time the ship, the *Viking*, drifted very little; for some time she was even carried slowly north-westwards towards the coast; on July 2nd, 1882, the position was 66° 48′ N. Lat. and 30° 35′ W. Long, while on July 7th it was 66° 50′ N. and 32° 35′ W.; on July 9th it was even 66°

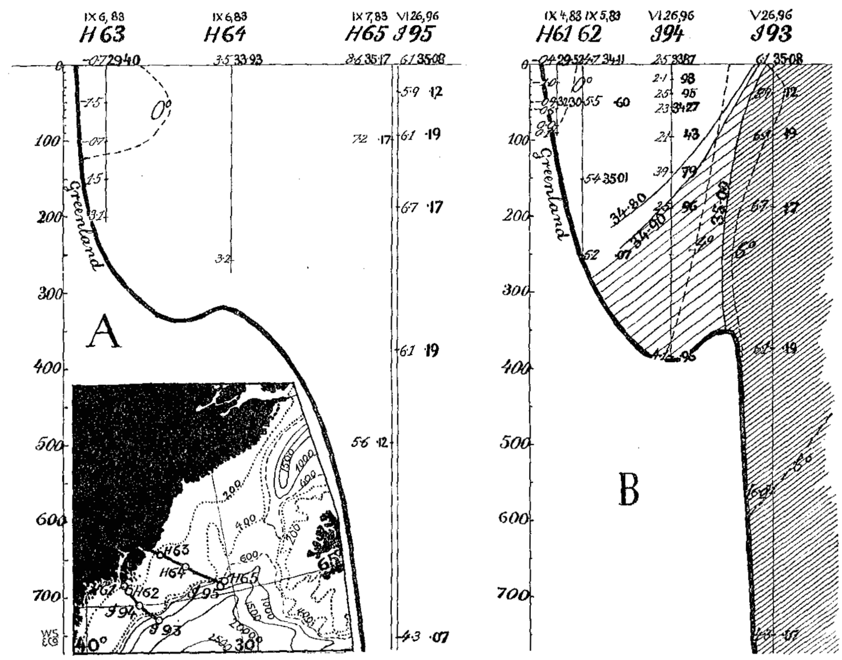

Fig. 103. Sections from the East Coast of Greenland, *A* through HAMBERG'S Stats. 63—65, and the *Ingolf* Stat. 95, *B* through HAMBERG'S Stats. 66—62 and the *Ingolf* Stats. 94—93. September, 1883, and June, 1896. Scales same as in Fig. 95. The chart shows positions of sections, and the isobaths of 200, 400, 600 metres, &c.

51′ N. and 32° 18′ W. so she had then been carried a little towards the north-east. But after that time she was carried slowly southwards to 66° 20′ N. and 32° 35′ W. on July 13th, and four days later she got out of the ice again. It seems as if there has been a kind of eddy in the current in this region, and the current has probably been much influenced by the tidal variations, just as is indicated by the observations during the *Belgica* expedition, on the continental shelf off the northern east coast of Greenland [cf. HELLAND-HANSEN and KOEFOED, 1909].

During NORDENSKIÖLD'S expedition to Greenland in 1883, Dr. AXEL HAMBERG took some observation-stations in and near the Polar Current along the east coast of Greenland, just south of Denmark Strait (cf. the small map, Fig. 103). We have given the observations taken by HAMBERG at these stations in Fig. 103, A and B; but as there are too few observations of salinity, no conclusions can be drawn from them as regards the volume of the current or its velocity. HAMBERG'S temperatures seem, to indicate that the current has a quite remarkably small volume in this region, and much smaller in the most southern section (B), off Angmagsalik, than in section B farther north (cf. the isotherm of 0° C.) But the observations of salinity at the Ingolf Stat. 94 prove that the current may have a greater width than HAMBERG's observations seem to indicate. The observations of temperature (varying between 2·1 and 3·9-° C., between 0 and 200 metres) at this station shows that the Polar water with salinities below 34·90 ‰ has been much heated on its way southwards through Denmark Strait, probably chiefly by intermixture with warmer waters. Unfortunately there are no other physical observations of importance in this part of the East Greenland Polar Current.

It seems, however, as if the very narrow current in HAMBERG's Section off Angmagsalik (Fig. 103, B) may run with great *velocities*, which may to some extent make up for its very small sectional area. In July, 1888, Nansen drifted, on the ice, with this current southwards along the Greenland east coast, from 65° 35′ N. Lat. and 38° W. Long. to 61° 35′ N. Lat. and 42° W. Long., during 11 days, from July 18th to 29th [cf. NANSEN, 1890]. The average velocity of the drift during those days was nearly 24 naut. miles in 24 hours (or about 50 centimetres per second), and during most days the velocities were even greater, about 26 or 27 naut. miles in 24 hours.(1) These are very much greater velocities than were found in the Polar Current off the east coast of northern Greenland (cf. p. 270). As there was very little wind during NANSEN's drift [cf. MOHN in MOHN and NANSEN 1892, p. 52], the great velocities of the drift cannot have been due to the wind, but must have been the velocities of the regular current.

6. The Ice.

The *ice* occurring in the region of the East Greenland Polar Current and east of it, is of two different kinds, *viz. North Polar Ice* coming from the North Polar Basin, and what we may call *Arctic Ice*, (also called *Bay-Ice*) which is formed in the northern and western

(1) The ship-wrecked whalers of 1777, drifted along the same coast with an average velocity of about 18 naut. miles in 24 hours, while the *Hansa* crew, in the winter of 1870, drifted with a mean velocity of only 4 or 5 naut. miles in 24 hours. The explanation may be that they were in the slower part of the current nearer land, and also that the current is slower in the winter than in the summer and autumn (cf. NANSEN, 1890, I, Chap. X).

regions of the Norwegian Sea — between Jan Mayen, Greenland, and Spitsbergen, and between Jan Mayen, Greenland, and Iceland.

The *North Polar Ice* forms extensive thick floes with great hummocks. The mean thickness of the floes may be 2 or 3 metres, or more, and the thickness of the hummocks perhaps 60 or 70 metres, or sometimes even more. This ice is several years old and has been formed in the North Polar Basin, from which it is carried southwards by the Greenland Current. In the Norwegian Sea it occurs as a rule only in the north-western and western region along the Greenland coast; and it occupies only the smaller part of the area which is covered by ice in the spring.

The *Arctic Ice* covers the greater part of this area. It consists of much thinner floes, about one metre thick, which have been formed n the Norwegian Sea during the preceding winter, and melt again during the following summer. Most ice met with in the sea north and north-east of Jan Mayen and between this island and Spitsbergen is of this kind, and so is also greatly the ice between Jan Mayen and Iceland. During the winter and spring great areas of the sea north-east of Jan Mayen, sometimes even as far as towards Bear Island, is covered by new formed ice, and this is the reason why the ice has, as a rule, such a wide extension in the spring (cf. the Danish Charts of the distribution of the ice). The rapidity with which the extent of the ice diminishes during the summer is due to the fact that this thin ice (containing much brine) melts comparatively easily, while the old, thick and humocky Polar ice takes a much longer time to disappear, and is carried by the Polar Current southwards along the east coast of Greenland.

The difference between these two kinds of ice is important, and ought to be taken into account by those who frame theories based upon the variations in the distribution of the ice. A good many false conclusions have hitherto been drawn by authors who have ignored this fact.

The *Melting of the Ice* in the East Greenland Polar Current is chiefly due to heat coming directly from the sun during the summers, and not to heat carried by the Atlantic water. This is clearly proved by the vertical distribution of temperature in the strata of the

Polar current [cf. NANSEN, 1906], and also by the seasonal variations in the temperature of the surface strata of the current. During the winter these strata are cooled to their freezing-point and much ice is formed, in the whole region of the East Greenland Polar Current as well as far outside it. By this process the salinity of the surface layers is increased, while it is again decreased by the melting of the ice during the summer.(1)

During the summer the surface layers are heated by the sun, as is clearly proved by all vertical series of temperatures taken in the East Greenland Polar Current in July and August during the many various expeditions (cf. above Table p. 274). Temperatures much above 0° C. occur in the surface between the ice-floes, and as deep as 5 metres, sometimes even below 10 metres. Owing to the admixture of the coast-water, this warm surface layer is generally deepest near the Greenland coast. These high temperatures are consequently entirely due to heat coming from above, during the summer. The fact is therefore that practically all melting of the ice is due to the heat coming from above, and not to the heat of the underlying warmer waters [cf. HELLAND-HANSEN and KOEFOED, 1909].

The *Belgica* Stations were all of them within the margin of the ice. At Stats. 30, 33, and 48 the ship was moored to small ice-floes, at Stats. 38, 43, and 44 she was moored to the coast ice, and at Stats. 40 and 42 she was in open lanes in the ice.

The NATHORST Stat. XI, was in the open coast-water inside the ice.

AMDRUP'S Stat. IV was in the ice, the ship was moored to an ice-floe. His Stat. II was in the ice, west of Jan Mayen about 100 feet from the nearest ice-floe.

RYDER'S Stat. VIII was in scattered ice, the ship was moored to an ice-floe. His Stat. XIV and XXVII were also in slack ice.

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(1) Some authors still frequently speak of the Polar water, with low salinity, carried by the East Greenland Polar Current as "water of ice-melting", evidently believing that it is formed by an intermixture of the nearly fresh water, formed by the melting of the Polar ice, with the waters of the Norwegian Sea. We have, however, seen that the main body of the Polar water flowing southwards along the east coast of Greenland is Siberian and American coast-water, whose salinity varies somewhat summer and winter according to the melting or formation of ice. The above-mentioned fact that the 32·0-isohaline forms such a very distinctly marked boundary-line of the Polar Current, even amongst melting ice-floes, also proves clearly how erroneous it is to assume that the Polar water is formed by ice-melting, because if it were not coast-water, it ought to have its lowest salinities near the outer boundary of the current were the melting is most active.

The following observations may be given as examples:

Depth in Metres				0	5	10	20	50
Belgica Stat. **30**	75° 39′ N.	12° 00′W.	July 22, 05	1·71	1·20	— 0·40	— 1·54	— 1·77
» Stat. **33**	76° 30′	14° 47′	» 24 »	1·02		— 0·16	— 1·04	— 1·74
» Stat. **38**	77° 36′	18° 12′	» 29 »	2·72	1·40	— 0·84	— 1·64	— 1·79
» Stat. **40**	78° 14′	14° 18′	» 31 »	1·03	0·93	— 0·41	— 1·63	— 1·74
» Stat. **42**	78° 07′	15° 06′	» 31 »	1·60		0·52	— 1·01	— 1·75
» Stat. **43**	78° 13′	16° 31′	Aug. 1 »	0·98	2·01	— 0·96	— 1·71	— 1·78
» Stat. **44**	77° 57′	17° 00′	» 2 »	2·10		1·87	— 1·14	— 1·78
» Stat. **48**	71° 23′	18° 58′	» 15 »	1·65		0·10	— 0·54	— 1·60
Nathorst Stat. **XI**	71° 36′	21° 15′	July 27, 99	2·16		1·13	[0·6]	— 1·65
Amdrup Stat. **IV**	74° 15′	16° 29′	» 10, 00	0·8	0·8	0·2	— 0·7	— 1·8
» Stat. **II**	71° 10′	9° 50′	June 29 »	0·3	1·8	0·7	— 0·1	— 1·6
Depth in Metres				**0**	**4**	**9**	**18**	**46**
Ryder Stat. **VIII**	72° 46′ N.	0° 13′ E.	July 4, 91	- 0.1	0·2	0.2	— 0·2	— 1·7
» Stat. **XIV**	74° 07′	17° 30′W.	» 19 »	1·4	0·7	— 1·0	— 1·3	— 1·7
» Stat. **XXVII**	69° 36′	19° 43′ »	Aug. 16, 92	0·8		0·4	0·1	— 1·7

These series illustrate without further explanation perfectly clearly how the waters of the Greenland Polar Current is heated from above during the summer, and how the melting of the ice must be almost entirely due to this heat.

The stations nearest the Greenland coast have the highest surface temperatures, often above 2° C, while the underlying water is very cold with minima of between — 1·6 and — 1·8° C. at 50 metres or deeper. These high surface-temperatures may be due to warm coast water coming from land, which also represents heat coming directly from the sun.

It is thus seen that practically no ice is melted by heat coming from the warmer water strata underlying the Polar water; the ice is melted by the direct radiation of heat from the sun during the summer. This heat either directly melts the ice on its surface, or as the vertical series of temperatures show, it heats the water between the ice-floes, down to 10 or 20 metres or more, and it also heats the surface-water coming from the coast. Thus a surface-layer of warm water is formed during the summer, in which the ice melts also on its underside.

The warm surface-layer always rests on much colder water. The above series show that at 20 metres the temperature is in most cases low, and at 50 metres there is very much the same temperature at all stations, the minimum temperature of between — 1.6° C. and — 1·8° C. occurring at this depth or slightly deeper. There is hardly any difference in temperature between summer and winter at this depth.

As the warm surface-layer rests on these cold underlying strata it must be cooled from below. By the radiation of heat from the surface, it is also cooled from above during the winter, and will soon be cooled to its freezing-point, and ice will be formed. The fact that ice is formed and no ice is melted during the winter also proves clearly that the heat coming from the underlying warmer water is of little or no importance for the ice-melting.

It is consequently a mistake to assume, like Prof O. PETTERSSON and some other authors, that the melting of the Polar ice directly cools the underlying warmer water-masses of the Norwegian Sea(1), or that it even forms the cold bottom-water. The melting of the ice during the summer engages a great deal of the heat coming directly from the sun, and thus prevents the heat wave from penetrating very deep in the sea in that region, and the sea-water is less heated during the summer than it would have been if there had been no ice. In this manner the cold water of the East Greenland Polar Current keeps its low temperatures on its southward course much longer than would have been the case if there had been no ice. On the other hand the cover of ice protects the underlying sea against the cooling by radiation of heat from the surface during the winter; and much heat is moreover disengaged by the formation of new ice. This counterbalances to some extent the cooling effect of the ice-melting in the summer.

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(1) Prof. PETTERSSON will even explain the under-current of intermediate warm water, underlying the East Greenland Polar Current, as a product of the ice-melting process. What has been stated above proves the impossibility of this theory sufficiently clearly, without any further discussion.

X. The Cyclonic Systems of the Southern and Northern Norwegian Sea.

On several occasions in the preceding Chapters we have mentioned the great cyclonic systems of the Norwegian Sea. As they form some of the most characteristic features in the physiognomy of the whole of this sea, we shall here embody in a special description the results at which we are arrived.

The principal currents in the Norwegian Sea are, the *Norwegian Atlantic Current* running along the whole of the eastern side-slope of the Norwegian Sea, and the *East Greenland Polar Current* along its western side-slope. The main bodies of these currents follow the edges of the continental shelves. In this manner we get as the primary great system of circulation, a cyclonic movement round the whole of the Norwegian sea-basin, along its side-slopes. This was clearly pointed out by Professor Mohn. The cyclonic direction of the movement is determined by the Earth's rotation. The relative volumes of the two currents are seen in Pl. XXV, Section IV.

This great primary system is divided in several smaller systems in which the water-masses also move in cyclonic directions. Cyclonic systems of this kind occur in the southern Norwegian Sea, in the Greenland Sea (northern Norwegian Sea), and probably also in the Iceland Sea.

The division in these different cyclonic systems is probably to a great extent due to the topographic features of the sea-bottom. Ridges and elevations projecting seawards from the continental slope are of special importance in this respect, as they impede the free course of the current even where they lie very deep, for it is evident that a current runs most freely over a deep sea, and it is checked in its course wherever the sea becomes shallower, even though slightly. Impeding formations of this kind are (cf. Fig. 8), the Helgeland Ridge west of Lofoten, the suboceanic ridge between Spitsbergen and Greenland, the Jan Mayen Platform, the suboceanic ridge between Greenland and Scotland with the Iceland and Færoe Platforms. At these places the currents are checked in their course, and some part of the water-masses is compelled to move towards the side. Thus the bathymetrical features give a natural devision of the whole Basin of the Norwegian Sea into separate smaller areas, that have their separate cyclonic current systems. In this manner the greatest vortex-movements mentioned before (in Chaps. VI, VII, and IX) are formed. But within these cyclonic systems a great many smaller vortex-movements arise, and in every current there seems to be continually changing movements, with formation of comparatively small vortices (cf. Chap. VI). Some of these smaller vortices may also be caused by the configuration of the bottom.

The Cyclonic Circulation System of the Southern Norwegian Sea.

The great cyclonic movement in the *Southern Norwegian Sea* is, on its eastern side, formed by the Norwegian Atlantic Current. At about the Arctic Circle a part of the current is forced towards the northwest, then westwards, and south-westwards.(1) On its western side the great vortex is bounded by the Arctic water mentioned in Chap. IX. The transition between the Atlantic water in this western region and the Arctic water is somewhat indistinct. We have mentioned that the East Iceland Arctic Current follows the edge of the continental shelf and the continental slope, and that its velocities are great along a narrow belt close to the latter; while they decrease

(1) In his chart of the Sea Currents, Capt. C. RYDER [1901, Pl. XI] has an arrow indicating a westward cyclonic current off Lofoten, which is too far north but otherwise remarkably correct. We do not know, however, how RYDER has got the idea of this current, or whether it is merely guess-work.

rapidly over the greater depths towards the axis of very heavy and cold water, extending towards the south-east from our Stat. 13 in Fig. 99. Between this axis and the western part of the great southern cyclonic system are the water-masses probably moving slowly north-wards, as we have indicated in Fig. 39. This movement was not introduced in our current-chart Fig. 2, as we did not consider it sufficiently certain, when we drew that chart years ago. There are, however, several facts that make the existence of this movement very probable, especially the distribution of the density, as is shown by the sections north-eastwards from Iceland (cf. Figs. 99 and 101). Our charts of the mean density of the upper 300 and 600 metres in Pls. IX, X, and XII prove the probability of a northward movement in about 5 and 6° W. Long., along the eastern side of the axis of heavy, cold water (cf. Pl. XIII). The distribution of the Arctic water (of the "tongue") in the chart for 200 metres of May, 1904 (Pl. XII), also indicates that the Arctic water has been carried towards the north-west from about 64° N. Lat. and 2° W. Long. The surface-charts in Chap. XI, Figs. 108, 109) also show a wide westward distribution of the Atlantic water, south of Jan Mayen, in about 68 and 69° N. Lat., just where we should expect to find it. It agrees with the results of our dynamic calculations which show a northward movement of the surface-layers in relation to the deeper strata, in the western part of the Lofoten section, east of the axis of heavy cold water. If there is not such a northward movement of the water on the western side of the cyclone, it would also be difficult to understand in what direction all the water flows away, which is carried into the central part of the cyclonic movement.

Fig. 104 represents the main features in the direction of the movement in the upper 300 metres, of the southern Norwegian Sea, according to our view. We have used the chart (Fig. 32) of the average horizontal distribution of salinity at 300 metres, resulting from all our observations taken during the years 1900—1904, and have in this chart drawn arrows indicating the directions of the great movements, leaving the details out of consideration; the small vortex-movements are consequently not represented in this chart.

It is remarkable how perfectly this chart of the movements,

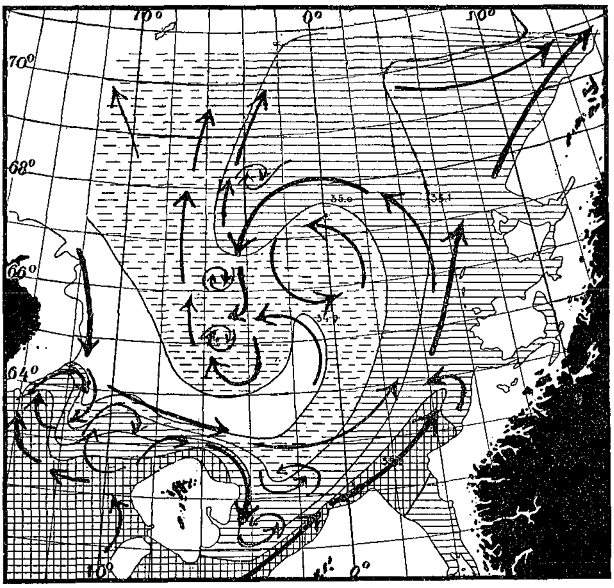

Fig. 104.
Average Horizontal Distribution of Salinity at 300 Metres, resulting from all Observations taken in 1900—1904. Arrows indicate Average Direction of Currents in upper 300 Metres.

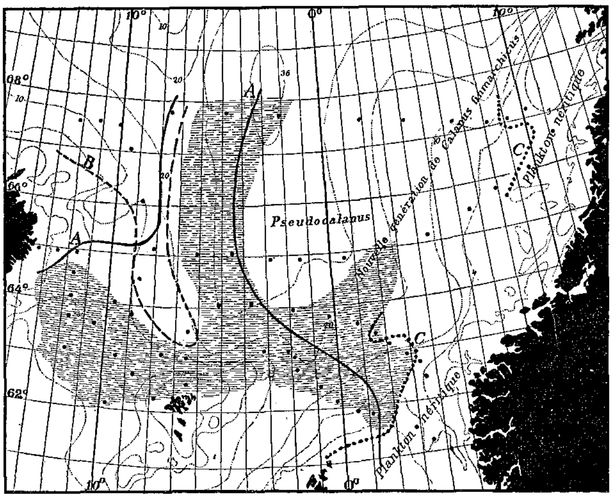

Fig. 105.
Distribution of *Calanidæ* at the Surface of the Southern Norwegian Sea, according to Damas. The lines mark the boundaries of regions where the different species abound, *A* adults of *Calanus finmarchicus*, *B* *Calanus hyperboreus*, *C* Neritic Plankton. The broken hatching indicates the distribution of larvæ of *Calanus finmarchicus* [Damas, 1905, Pl. I].

which is based entirely upon our physical observations, agrees with Damas's chart [1905, Pl. I] of the distribution of *Calanus finmarchicus*, *Calanus hyperboreus*, and *Pseudocalanus* (cf. Fig. 105). When he wrote his interesting paper, Damas did not know in the detail the results of our investigations as regards the movements of the waters in the southern Norwegian Sea, he only knew our discovery of the great cyclonic system. He could not therefore give a detailed explanation of the distribution observed. We think that our system of circulation gives a quite natural explanation. According to GRAN's [1902] and DAMAS's investigations it seems as if there are different species of Plankton organisms, *e. g. Calanidæ*, that are quite characteristic for certain areas in the open sea; within these areas they abound, while they are comparatively rare outside them. We may assume that they are in a way stationary there. We can only explain this fact by assuming that the water-masses of those areas are also more or less stationary, and are renewed comparatively slowly. We have found in the southern Norwegican Sea especialy three different areas where there is probably a very slow renewal of the water-masses, and where a great part of the water probably remains for a long time, exposed to circulatory movements in various directions. These three areas are:

(1). The central part of the great cyclonic system, between about 65 and 67° N. Lat. and 2° E. and 3° W. Long. (cf. Fig. 104). The water of this areas is chiefly Atlantic.

(2). The boundary region between the western side of the great cyclonic system and the axis of cold and heavy Arctic water. This area extends northwards, from about 64° (or even 63°) N. Lat., between 3° and 7° W. Long. The water of this area is a mixture of Atlantic water and Arctic water.

(3). The axis of cold and heavy Arctic water extending south-eastwards from the sea between Iceland and Jan Mayen (cf. the isopyknal of 27·90 in the chart of mean σ_t for 0—300 metres in Pl. XII; see also Pl. XIII, the isotherm of 0° C. at 100 metres and the isopyknal of 28·00 at 200 metres).

(4). In addition to these areas we may also mention the area over the Færoe-Iceland Ridge, on the boundary of the Norwegian Sea, where vortices, chiefly anticyclonic, are formed (cf. Fig. 107), and where the water-masses probably to some extent are fairly stationary, circulating in these vortices. The waters of this area are formed by intermixture of Atlantic water with Arctic water.

If we now look at DAMAS's chart (Fig. 105) it is striking how exactly his areas of the three kinds of *Calanidæ* coincide with the four areas just described. *Pseudocalanus* is stationary in the central water chiefly of Atlantic origin, in our central area 1 of the cyclonic system. *Calanus hyperboreus* is stationary in the axis of cold and heavy Arctic water described as our area 3. DAMAS's boundary-line (Fig. 105, *B*) of the area of this species coincides almost exactly with the equilines mentioned above. *Calanus finmarchicus* is evidently stationary in the mixed waters of Arctic and Atlantic origin, in our areas 2 and 4. From these areas the larvæ and young individuals are carried with the current eastwards into the region of the Norwegian Atlantic Current, where, however, this species cannot be considered as being stationary, as shown by DAMAS's boundary-line (Fig. 105, *A*) of the region of the adults.

DAMAS's statements seem thus to be an excellent verification of the correctness of our results as regards the movements and circulation of the water of the upper strata in the Southern Norwegian Sea.

The Cyclonic Circulation System of the Northern Norwegian Sea.

The cyclonic system of the Northern Norwegian Sea, or Greenland Sea, seems to be quite as complicated as that of the Southern Norwegian Sea just described; but we have a much more incomplete observation-material from that part of the sea, and cannot therefore trace the details of its cyclonic system.

As Fig. 93 shows, it is formed, on its eastern side, by the Spitsbergen Atlantic Current running northwards, and on its western side by the East Greenland Polar Current and its underlying warmer water-strata. North of Jan Mayen the Polar Current gives off an eastward branch, the Jan Mayen Polar Current, bounding the cyclonic system on its southern side, and west of Spitsbergen the Atlantic Current gives off a westward branch forming the northern boundary of the cyclone (Fig. 93). But within this great cyclonic system there is evidently smaller vortex-movements.

Ia about 75° N. Lat. a part of the surface-strata of the Atlantic Current extends westwards (cf. Fig. 93, Surface, 50, 100 m.; and Figs. 108, 109), and evidently forms to some extent a kind of a vortex-movement, water from the Jan Mayen Current probably extending far eastwards to the south of this region. Indications of the westward extension of the Atlantic water in about 75° N. Lat. (or between 74 and 76° N.) is distinctly seen in nearly all our surface charts of the various years (see especially Figs. 108, 109, and May, 1902, Pl. VI); and the surface chart of the summer of 1905 published in the *Belgica* Report [HELLAND-HANSEN and KOEFOED, 1909] gives an excellent representation of this westward flow of Atlantic water (see our Fig. 93). In HAMBERG's surface chart [1906] there is also a wide extension westward of water with salinity above 35 ‰ in about 75° N. Lat.

The westward movement of the Atlantic water in this region has a certain resemblance to the westward movement of the Atlantic water west of Lofoten. It coincides in a remarkable manner with the position of the hypothetical low elevation on the sea-bottom, which we have drawn in our bathymetrical chart (Pl. I) as a low ridge extending towards the southwest into the Greenland Deep from the continental slope, off Spitsbergen (cf. p. 74). The assumption of the existence of this low ridge is, however, based only on a few soundings.

The branch of diluted Atlantic water running westwards and south-westwards in the sea west of Spitsbergen was discussed in the preceding chapter. At the surface it appears to be smaller than the westward branch in about 75° N. Lat. (cf. Fig. 93), but at the deeper levels it is more conspicuous. As was pointed out above it sinks under the Polar Current and forms the intermediate warm water-layer. The formation of this branch west of Spitsbergen also coincides with an elevation or ridge on the sea-bottom extending westwards from the continental slope, off the northern end of Prince Charles Foreland (cf. Pl. I).

North of this ridge there seems to be a small vortex or an eddy, frequently carrying Polar water in towards the Spitsbergen coast from the west (cf. Figs. 93, Surface, and 106). At the northwest corner of Spitsbergen, just south of 80° N., another small branch of diluted Atlantic water is probably given off towards the north-west and west, along the slope of the Spitsbergen Greenland Ridge. The rest of the Atlantic water runs towards the north-east, across this ridge, into the North Polar Basin.

The east Greenland Polar Current forms evidently similar small vortices with eastward branches (cf. Fig. 93).

The central part of the great cyclonic system of the northern

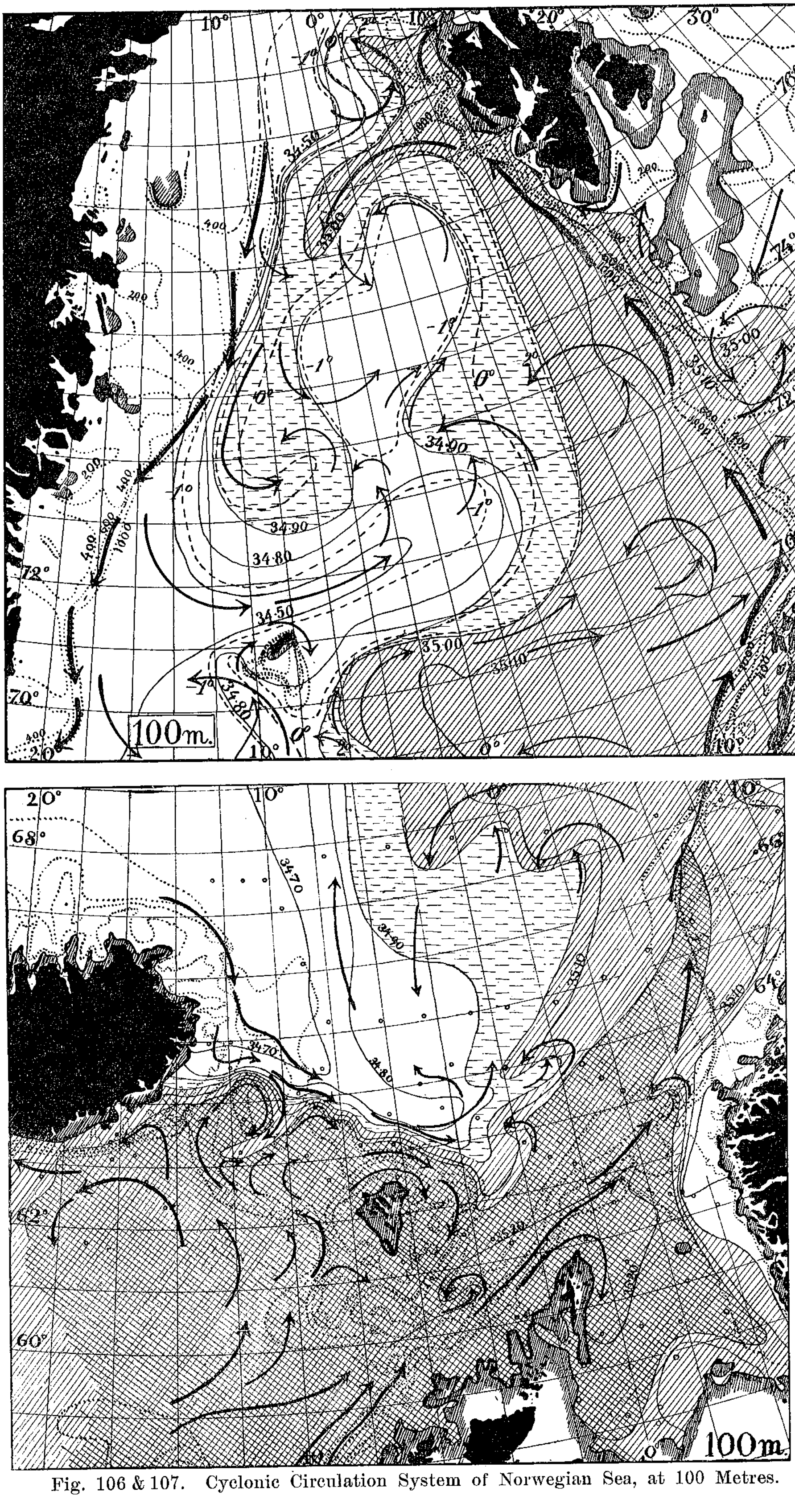

Fig. 106 & 107. Cyclonic Circulation System of Norwegian Sea, at 100 Metres.

Norwegian Sea is the area where the bottom-water is formed during the winter, as will be mentioned in the following chapter; and it was just in this region that Roald Amundsen took his stations in 1901 [cf. Nansen, 1906]. The Arctic water forming the surface layers of this central area is formed by an intermixture of Atlantic water coming from the west (in about 75° N.) and Polar water carried by the Jan Mayen Polar Current. The salinity of this Arctic water is raised during the winter by formation of ice, but is lowered during the summer by the melting of the ice again.

The socalled "Bay-Ice-Bight" ("Bay-Is-Bugta") of the sealers corresponds to this central area, or rather to the west-ward branch of Atlantic water generally beween 74 and 76° N. Lat. And the "Ice-Tongue" ("Is-Odden") of the sealers is probably due to the Jan Mayen Current which carries ice eastwards into a projecting tongue, where the seals *(Phoca groenlandica)* gather in March in order to bear their youngs, and where hundred thousands of them have been killed every year. As a rule this "Ice-Tongue" is in about 72 or 73° N. Lat. But the sealers have found great variations in the position of the "Is-Odde" and the "Bay-Is-Bugt" in the different years, and we may therefore assume that there are variations in the course and extent of the abovementioned currents.

Fig. 106 represents the horizontal distribution of salinity at 100 metres below the surface, and the movements in the cyclonic system of the northern Norwegian Sea according to our investigations. By uniting this figure with Fig. 107 (Fig. 39) we obtain a fairly complete representation of the cyclonic circulation systems in the southern and northern Norwegian Sea, which is probably more correct in detail than Fig. 2.

Cyclonic System of the Iceland Sea.

We have mentioned above that there are probably similar cyclonic movements in the Iceland Sea, between Greenland, Jan Mayen, and Iceland, and that only in this manner we can explain the wide distribution of the surface-layers of Polar or Arctic water in this region. The axis of cold and heavy Arctic water extending south-eastwards into the southern Norwegian Sea evidently also belongs to this water, and is more or less formed by an intermixture of Polar water with water originally coming from the Atlantic Current, this mixture has acquired a low temperature by cooling during the winter. As will be mentioned in the following chapter it is possible that bottom-water may be formed in the sea between Iceland and Jan Mayen, which also indicates that it belongs to the central waters of a cyclonic system, because bottom-water can only be formed where the water is fairly stationary, and where there is only a very slow horizontal circulation [cf. NANSEN, 1906]. But as very few observation-stations have been taken in the Iceland Sea, we can say nothing certain about its cyclonic system.

XI. The Bottom-Water of the Norwegian Sea.

Its Distribution and Formation.

This water with a nearly uniform density had, as mentioned above, already been discovered on our first cruise in 1900. It forms a very important feature in the Oceanography of the Norwegian Sea. It fills more than two thirds of the volume of the entire basin, and is found everywhere below certain depths forming the floor over which the warm Atlantic Current, as well as the cold Polar Current (with its underlying warmer water) move (cf. Pl. XXV). The characteristics of this Bottom-Water are its *low temperature*, between 0° and —1·3° C., and its very *uniform salinity* of about 34·92 ‰, varying perhaps between 34·90 and 34·94 ‰. Its upper boundary may be assumed to be marked approximately by the isotherm of 0° C. where the salinity may vary between 34·90 and 34·94 ‰ (or perhaps even 34·95 ‰). The depth at which this boundary lies, varies in the different regions of the Norwegian Sea. It lies on the whole deepest under the warm Atlantic Current along the eastern side of the basin. Here the bottom-water forms, so to speak, a deep channel in which the warm current runs. This "channel" is shallowest in the southern part of the basin (Pl. XXV, Sect. I). Between Norway and Iceland it is generally about 600 or 650 metres deep (see Sections, Fig. 1 on Pls. XIVA, XVI, XVII, XVIII, XX, XXI A, XXII, XXIVA), while farther north, between Vesteraalen and Jan Mayen (Pl. XXV, Sect. II) it is about 1000 or even 1100 metres deep at its deepest, and off Bear Island it may be 900 or 1000 metres deep. Off Spitsbergen it is probably somewhat shallower about 900 and 800 metres, and north-west of Spitsbergen it is still shallower, about 800 metres.

In the regions west of the Atlantic Current the bottom-water rises to much higher levels; and in the sea north and north-east of Jan Mayen, it even approaches the surface (cf. Fig. 95, and Pl. XXV, Sects. III and IV), especially in the winter and spring, when it fills the whole sea in that region, between the surface and the bottom, with water of a nearly uniform temperature and salinity.(1) This is the region where the bottom-water of the Norwegian Sea is chiefly formed.

Off the east coast of Iceland, and between the latter and Jan Mayen, the bottom-water frequently rises to levels of between 400 and 300 metres, below the surface, and during spring and summer, there is an axis extending from the sea east and north-east of Iceland northwards towards Jan Mayen, where the bottom-water rises to its highest levels in this southern part of the sea. Indications of this axis are seen in the chart for 400 metres on Pl. XIII (cf. the isotherm of 0 ° C.).(2)

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(1) It is possible that similar conditions may also at times occur in the sea between Jan Mayen and Iceland [cf. NANSEN, 1906, pp. 70—72].

(2) This chart is based upon the numerous observations from different years, and has been drawn with the aim of giving a fairly trustworthy representation of the *general features* of the horizontal distribution of temperature, salinity, and density. When the charts on Pls. III to XII were drawn, some years ago, sufficient attention had unfortunately not been paid to these conditions. The difference between the *Polar or Arctic surface-waters* with temperatures below zero, and the *bottom-water* with similar low temperatures, but with higher salinity, was not then sufficiently noticed. *They are two entirely different waters, which hardly ever come in contact with each other,* as they are separated by an intervening layer of warmer water. The isotherm of 0 ° C. is therefore evidently drawn somewhat incorrectly near Iceland in most of these charts and in some sections. Let us as an example take the Section for May, 1903, Pl. XXI A, Fig. 1. At the Danish Station Da 17 at 200 metres there was observed a temperature of -0.12 ° C. and a salinity of 34.87 ‰. This is evidently cold Arctic water, in part originating from the Polar Current and belonging to the upper layers about 200 metres thick. (The salinity is probably somewhat too high, as is the case with many salinities of the Danish Stations of that year, see above p. 32.) It is therefore entirely different from the bottom-water, which was found, for instance, at 500 metres at Stat. Da 10, having a temperature of -0.26 ° C. and a salinity of 34.92 ‰. These two waters were most probably separated by water with a temperature above zero, and a salinity about or below 34.90 ‰, like the water observed at 300 and 250 metres, at Stat. Da 10. It is therefore incorrect to draw the isotherm continuously up to 200 metres at Stat. Da 17. The cold water at this depth should

Towards the Greenland coast the upper boundary of the bottom-water again sinks to form a depression or "channel" for the water-masses of the East Greenland Polar Current, and its underlying warmer strata. The depth of this "channel" may be between 600 and 900 metres, according to the observations made during the cruise of the *Belgica* in 1905 (cf. Figs. 95, 96). Pl. XXV, Sects. III and IV, demonstrate the "channels" of the two currents on both sides of the Norwegian Sea, and the higher levels of the bottom-water in the region between them.

The manner in which the cold Bottom-Water of the Norwegian Sea originates has been discussed at length in Nansen's recent paper [1906, cf. pp. 85 *et seq.*], and it was proved that it is formed at the sea-surface by cooling, consequent on the radiation of heat from this surface, during the winter and spring. It is, in other words, what we might call a typical *winter water*, carried downwards by an active vertical circulation through water-strata having nearly uniform density between surface and bottom. We consider it unnecessary to again re-open this discussion here, as, according to our view, Capt. AMUNDSEN's important series of observations from the sea to the north and north-east of Jan Mayen, demonstrate with all desirable clearness the bio-genesis of this peculiar water. There is, however, one interesting point to which we have some rather important observations to add. At the time when AMUNDSEN's observations were taken (June and July, 1901), the typical cold "bottom-water" with temperatures below — 1 ° C. was covered by a top layer of water with a lower salinity and mostly with a higher temperature (see Fig. 95, and Pl. XXV, Sects. III & IV). This layer was generally more than 150 metres thick. Its occurrence was evidently due to the fact that the formation of the cold, heavy water, by the cooling of the sea-surface, had ceased some time ago. This cold water was sinking towards a level of equilibrium at greater depths, and near the surface, had been replaced by lighter water which to some extent had already been diluted by the melting of the

have been surrounded by a separate, closed isotherm of 0 ° C., whilst the zero-isotherm at Stat. Da 10, should have been drawn more or less horizontally westwards, hardly rising above the 400 metres line. In the Section for August, 1903 (Pl. XXII, Fig. 1), a similar error is made in the isotherm of 0 ° C., which should not rise upwards towards 200 metres at Stat. Da. 17 (cf. above pp. 292, 299).

ice. Nansen considered it, however, to be evident that during the previous winter and spring, the cold, heavy bottom-water must actually have reached the sea-surface in this region. The correctness of this view is proved by the previously mentioned (p. 25) surface-observations collected from this region by the captains of sealing-vessels. The numerous observations thus obtained give valuable information concerning the horizontal distribution of temperature and salinity on the sea-surface in this interesting region during the spring and early summer.

Our description, in Chap. X, of the cyclonic circulation system of the northern Norwegian Sea (Greenland Sea) shows that there is a central area in this region, where the water has probably very slow horizontal movements (cf. Figs. 93, 106), and its renewal takes a comparatively long time. Owing to the influx of Atlantic water from the west, the salinity of the surface-layers of the area is comparatively high. There is consequently exceptionally favourable conditions for the formation of heavy surface-water by the cooling and the formation of ice during the winter. The correctness of this assumption is proved by all observations taken in the early spring.

As a general rule it may be stated that whenever, in the months of March, April, or the first part of May, observations have been collected from the sea north and north-east of Jan Mayen, (between 72° and 75° N. Lat. and between 2° E. Long. and 8° W. Long.), very low temperatures, between −1·2 and −1·9° C., were found in the sea-surface, whilst the surface-salinity was generally between 34·7 and 34·9 ‰. In other words, *the formation of cold, heavy bottom-water was here directly observed on the very sea-surface,* as was previously expected, *and the question of the process of its formation is thus finally settled beyond all doubt.*

Valuable observations of this kind were especially taken during the cruises of the "*Hekla*" and the "*Capella*" from March to May, 1901, and of the "*Vega*" from March to May, 1902. Observations taken during the cruise of the "*Rivalen*" in May and June, 1903, are also interesting, as they show that even as late as June 1st, temperatures of about −1·5° C. and a salinity of about 34·78 ‰ may be found in 76° 10′ N. Lat. and 1° 0′ E. Long.; and on May 20th surface-temperatures sinking towards the freezing-point of the sea-water, and salinities of about 34·81 and 34·83 ‰, were observed in 74° 35′ N. Lat. and 0° 50′ E. Long., and in 74° 55′ N. Lat. and 4° 0′ W. Long.

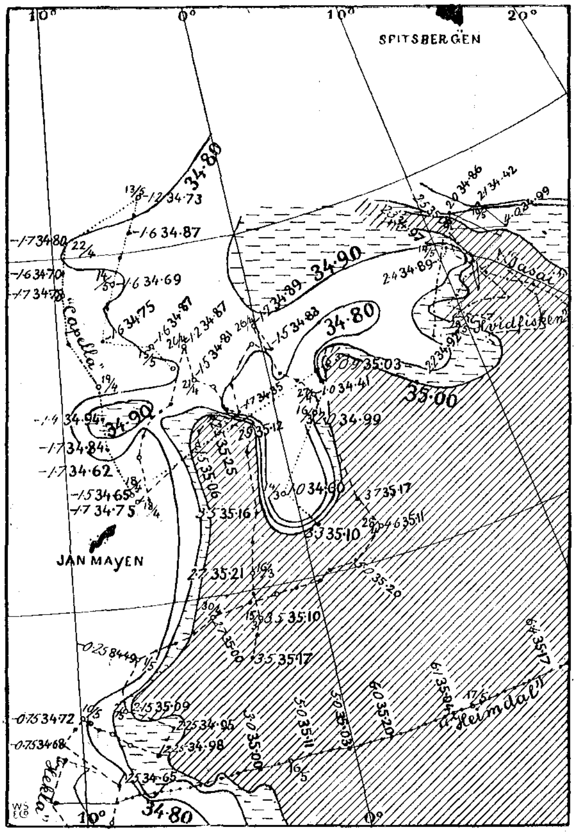

Fig. 108. Surface-Observations in March—May, 1901, of the *Capella*, *Hekla*, *Jasai*, *Hvidfisken*, and *Heimdal*. Single hatching indicates salinities above 35·00 ‰, broken hatching between 34·90 and 35·00 ‰.

The observations of the first three cruises are introduced in Figs. 108 and 109 (cf. also the charts on Pls. V & VI). The observations taken independently during the two cruises of the *Capella* and *Hekla* in March, April, and May, 1901, agree very well, and show that at that time the sea between 72° and 75° 18′ N. Lat. and between 2° E. Long. and 6 or 8° W. Long., was largely covered with surface-water which had temperatures generally between — 1·25 and — 1·6° C. and salinity between 34·8 and 34·9 ‰. Only one observation (the *Capella* on April 19, 1901, — 1·4° C. 34·94 ‰) gave a salinity above 34·9 ‰ for cold water with temperature below — 1° C.; but salinities as high as 34·87 and 34·89 ‰ for this cold surface water, were quite common in the series of observations of both ships. The thermometers have evidently been read off somewhat roughly during these cruises and the temperature-values cannot therefore be considered as being very accurate. The water-samples were brought home on small medicine bottles with cork stoppers. There may have been some evaporation through the cork-stoppers, and the high salinity found in some cases may be thus explained. The water-samples may, on the whole, have had a tendency to give somewhat too high salinities, for the same reason. That has evidently also been the case to some extent in the following year (the water-samples of the *Vega*).

The observations of the *Vega* during March, April, and May of the following year, 1902, in the same region, give on the whole higher salinities, frequently about 34·95 or even 34·97 ‰ (which are probably somewhat too high) with very low temperatures, even — 2·0° C. (which should evidently be about — 1·8 or — 1·9° C.). The sea-surface may possibly have been colder in the spring of 1902 than in the previous spring, and there may have been a more rapid ice-formation to increase the salinity of the surface-water.

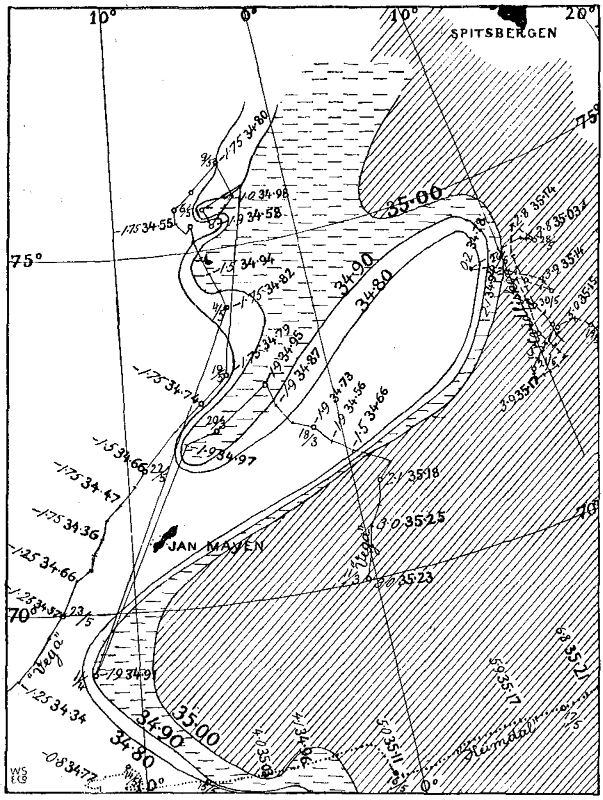

Fig. 109. Surface-Observations, March—May, 1902, of the *Vega*, *Hvidfisken*, and *Heimdal*. Single hatching indicates salinities above 35·00 ‰, broken hatching between 34·90 and 35·00 ‰.

The principal features of the course of the isohalines and isotherms on the sea-surface are, however, fairly similar in the two years. In both charts there is an especially conspicuous area to the north-east of Jan Mayen, about 72° N. Lat. and the Meridian of Greenwich, where the salinities are very low, below 34·8 ‰ and even as low as 34·41 and 34·35 ‰ (April, 1901). This is evidently Polar water carried by the Jan Mayen Polar Current which runs eastward in this region of the sea, between 71° and 74° N. Lat., (cf. above p. 319), and joins the cyclonic circulation round the central area of heavy water where the bottom water is generally formed.

In the chart of March—May, 1902 (Fig. 109), the course of this current is neatly demonstrated by the isohalines of 34·80 and 34·90 ‰ based upon the observations of the *Vega* and *Hvidfisken*; but there were comparatively few observations and the equilines have consequently got very regular shapes (cf. above p. 128). In March—May, 1901, there were many more observations, the isohalines have consequently much more complicated shapes in Fig. 108. A very conspicuous feature that year, in March, are two tongues of water with high salinities(1) and high temperatures (2·5° and even 3·0° C.) extending far northwards in the region west of Jan Mayen. Between these two tongues there was an apparently isolated patch of water with salinities as low as 34·60 and 34·35 ‰. We consider it proaable that by some kind of disturbance the warm Atlantic water has been carried some distance northwards across the cold waters (with low salinities) of the Jan Mayen Polar Current.

(1) The salinities observed, 35·22 ‰ and 35·25 ‰, are hardly possible in this region, and the values are probably too high. Errors may have been caused by evaporation through the cork stoppers of the bottles on which the water-samples were brought home.

Anticyclonic vortex-movements may also have been formed. The observations of the *Jasai* and *Hvidfisken* farther east give comparatively low salinities in May that year, and seem to indicate that there was comparatively little Atlantic water in that region.

North of the waters of the Jan Mayen Current a tongue of water with higher salinities extends far westwards. This is the westward branch of the Atlantic Current (in about 75° N. Lat.) which was mentioned in Chap. X (p. 316). In March, 1902, the temperature of this tongue was very low, about $-1{\cdot}9°$ C. The salinity was about 34·95 and 34·97 ‰, if the values are not somewhat too high. At that time "bottom-water" was consequently rapidly being formed in this tongue.

On April 11, 1902, an interesting observation of $-2°$ C. (should be somewhat higher) and 34·91 ‰ was taken on the surface in 69° 8′ N. Lat. and 11° 45′ W. Long. Provided that this observation be approximately correct, it indicates that "bottom-water" may also be formed in the sea between Jan Mayen and Iceland, the probability of which Nansen had previously [1906, pp. 70—72] assumed, judging from two vertical series of temperatures taken by RYDER in June, 1891, and some observations taken during the *Ingolf* Expedition.

It will thus be seen that where the conditions are favourable, the bottom-water of the Norwegian Sea is formed at the sea-surface by the radiation of heat, during winter and spring.(1) The process may to some extent be assisted by the formation of ice which gradually increases the salinity of the surface-strata, these having been diluted during the summer partly by the admixture of Polar water from the Polar Current, and partly by the melting of ice. But on the other hand the formation of ice where the ice-cover remains, will greatly retard the cooling of the underlying waters by preventing them from coming to the surface, and being directly exposed to the radiation of heat.(2) The most effective cooling and most rapid formation of bottom-water, will therefore take place where the salinities of the

(1) Professor O. PETTERSSON has suggested [1904] that the typical "bottom-water", of about $-1{\cdot}2°$ C. and 34·90 ‰, at depths between 100 and 2000 metres, at AMUNDSEN'S Stations 13—23, in the sea north of Jan Mayen, might be Polar water coming with the Polar Current from the North Polar Basin. Even if the impossibility of this hypothesis had not been proved by several facts already known [cf. NANSEN, 1906, p. 88, and Sections V, VIII, and IX, Pls. VII—X] the numerous observations made in the sea to the north of AMUNDSEN'S region during the expedition of the Duke of ORLEANS, in the summer of 1905, prove with final certainty that no current of the description suggested by PETTERSSON, exists (cf. Fig. 93). Everywhere to the north and north-west of the region of Amundsen's Stations 13—23, a thick layer of comparatively warm water was found underlying the top layer of cold and less saline Polar and Arctic water. [See HELLAND-HANSEN and KOEFOED, 1909.]

(2) The cooling of the underlying water will also be retarded by the disengagement of heat during the freezing-process, but this is naturally of less importance.

surface-strata have been raised to about 34·9 ‰ and where an active vertical circulation keeps the sea open, preventing the surface-waters from being cooled to their freezing-point and thus being covered with ice. It is evident that the wind may also be of importance in this respect by breaking the ice, and carrying it away so that open places are formed where the water-surface may again be directly exposed to the radiation of heat. In this manner the sea-surface may be swept open in areas where the surface-strata in the beginning of the winter had such low salinities that much ice had to be formed before a sufficiently high salinity, of nearly 34·90 ‰, could be produced, enabling the vertical circulation to break through the less saline top layer and reach down to the bottom-water.

It is evident that the cooling of the underlying water caused by the contact with the underside of the ice, cannot be so effective as the cooling caused directly by radiation from the surface; but on the other hand, where the ice descends below the surface-strata, water may be cooled to the density of the bottom-water in this manner, even where the surface-water has a lower salinity.

We can only expect to find the above conditions, necessary for the formation of the bottom-water of the Norwegian Sea, near the eastern margin of the East Greenland Polar Current, especially in the sea between Jan Mayen and Spitsbergen (and perhaps occasionally to some small extent also in the sea between Jan Mayen and Iceland), where the cooling of the sea-surface during the winter is sufficiently effective, and where the sea-water does not contain too great a quantity of heat beforehand, and has a sufficiently high salinity to enable the vertical circulation to reach down to the necessary depths. For this purpose it is evidently also of importance that the cooled water is not carried away by a too rapid horizontal circulation, but remains fairly stationary, so that the vertical circulation is not too much disturbed by warmer or lighter water coming in from the sides.

We may expect to find the most favourable conditions in this respect, in the central area of the northern cyclonic movement of the Norwegian Sea, between Jan Mayen and Spitsbergen; for the water-masses of this central region are probably more or less stationary, having very little horizontal movement. This area is approximately indicated by the closed isotherm of -1° C. and the isopyknal of 28·10 in the charts for 300 and 400 metres, Pl. XIII, see also Figs. 93, 108, on pp. 283, 318.

It is clear that the density of the bottom-water of a deep sea-basin, like the Norwegian Sea, must determine the limit to which the density of the surface-water of the same sea may be increased. If therefore the surface-strata be cooled down towards their freezing-point, the increase of their salinity, by the formation of ice, cannot go on beyond the moment at which the surface-water has attained a density slightly greater than that of the underlying bottom-water, when it must sink towards the bottom. But as the density of sea-water alters only slowly with changes of temperature about or below -1° C., *the necessary density of this cold sinking water, forming the bottom-water, must chiefly depend on its salinity, which must consequently become more or less constant and uniform, wherever or whenever this kind of water is formed in the deep Norwegian Sea.*(1) Thus it is easily seen that whether the bottom-water be formed by the sinking of cold surface-water to the north of Jan Mayen, at different places, or perhaps between Jan Mayen and Iceland, it must always acquire very nearly the same salinity. It will also be easily understood that the salinity and density of the bottom-water of the Norwegian Sea must be nearly uniform, and cannot change much from one year to another. Even if the physical conditions on the surface of the sea change in the course of time, a very long period must elapse before this can produce much difference in the salinity and density of the bottom-water. If, for instance, during one year or during a period of years, the climate is much colder, thus lowering the temperature of the sea-surface, this will increase the quantity of sinking surface-water formed during the winters, but will not greatly change the salinity of this sinking water, nor necessarily make its temperature appreciably colder. If, on the other hand, the salinity of the surface-water be changed, this will not greatly alter the salinity

(1) In shallow enclosed seas, like the Barents Sea, or over the continental shelf, if there is a slow horizontal circulation, it may be different, and the heavy winter-water or bottom-water formed there may vary much, and may become exceptionally heavy where ice is formed, *e. g.* in the eastern Barents Sea [cf. NANSEN, 1906].

of the sinking water, but will chiefly have an influence upon the quantity formed; an increase of the surface-salinity tending to increase the quantity of sinking surface-water, while a decrease will have the opposite effect.

The Salinity and Specific Gravity of the Bottom-Water.

The numerous samples of the cold bottom-water of the Norwegian Sea collected in bottles with patent india-rubber stoppers during the cruise in July—September, 1900, were examined by Nansen's assistant, Cand. Real. JAKOB SCHETELIG, who determined their specific gravity by means of Nansen's Hydrometers of Total Immersion (see above, p. 66). The constants of the instruments employed had been determined some by Nansen (the hydrometer principally used) and some at the *Physikalisch-Technische Reichsanstalt* in *Charlottenburg* (some hydrometers from C. RICHTER, Berlin, used for control). Several determinations were generally made of each water-sample, and special care was taken to keep the temperatures of the samples as equable as possible during the observations [cf. SCHETELIG, 1901]. It is therefore to be expected that the values of specific gravity obtained should with few exceptions be accurate to within one unit of the fifth decimal place (*i. e.* within 0·01 of σ_0). The results of the determinations are given in the following Table (pp. 332 & 333).

The specific gravity (σ_0) of the deep waters (from depths greater than 1400 metres) varies in these observations as a rule between 28·05 and 28·07, and in some cases—Stations 29 (1530 metres) and 65 (1550 metres)—it even reaches 28·08. The salinity of the deep bottom-water should consequently vary between 34·91 ‰ and 34·93 ‰ or even 34·94 ‰. The observations show no certain regularity in these variations. The lowest values (28·05) of the deepest bottom-water were found at Stats. 9 and 9 A (north of the Færoes), and Stat. 34 (east of Jan Mayen). The highest values (28·07 and 28·08) were found at Stats. 29 (near Jan Mayen), 43 (between Vesteraalen and Jan Mayen), 46 (off Vesteraalen) and 65 (towards Bear Island). Medium values (28·06 and 28·065) were found at Stats. 8, 18 (between Iceland and Jan Mayen), 64, and 68. There may thus possibly be some tendency towards lower values along the southern and western side of the basin, at Stats. 9, 9 A, 10 (about 28·055 at 500 and 600 metres), 18, and 34 (for situation of stations see Pl. III) and higher values along its eastern side at Stats. 7, 47, 46, 43, and 65. The exceptions to this are Stat. 29, off Jan Mayen, where the values are comparatively very high, and Stats. 64 and 68 where they are low. In the vertical series, at the various stations, the rule is that the specific gravities of the bottom-water are higher in the higher strata with higher temperatures than in the deeper, colder strata. At depths between 600 and 1000 metres, σ_0 was as a rule between 28·065 (34·93 ‰) and 28·08 (34·94 ‰). The lowest values at these depths were observed along the southern and western sides of the basin, at Stats. 7, 8, 9, 10 (28·055 or 34·91 ‰), 17 (28·05 at 400 metres), 18, and 34; while Stats. 43, 46, 47, and 64 have high values (28·08 and 28·07). At Stats. 19 and 29, near Jan Mayen, the values were also comparatively high (28·07 and 28·075).

The *Chlorine (Halogen)* of the greater part of the samples was determined by Mr. I. LEIVESTAD by Titration (Mohr) in the autumn of 1901. These determinations, though carefully made, cannot be considered very accurate, especially as the samples (which were kept on bottles with patent india-rubber stoppers) had been used often several times before (during the previous winter and spring), for the determinations of the specific gravity, and some evaporation of the water had taken place.(1) The salinity computed (by Knudsen's Tables) from the values of chlorine thus obtained, are therefore probably somewhat too high on the whole. They are given in a special column in the Table. In another column are also given the salinities which Helland-Hansen found by the titration of special samples taken simultaneously from the same depths, and brought home on small medicine bottles with cork stoppers. The salinities obtained by LEIVESTAD'S titrations vary very irregularly between 34·92 (in a few cases even 34·91) and 34·96 ‰. These variations are evidently to some extent due to inaccuracies in the observations.

Helland-Hansen's titrations give more uniform salinities, especially for the samples taken during the latter part of the cruise, after Stat. 34. These samples were examined two or three weeks after they had been taken, and there could not have been any appreciable evaporation through the corks of the glass bottles in the mean time.(2) There have undoubtedly been some variations in the amount of chlorine (halogen) contained in the samples of the bottom-water; but we see nevertheless that by far the greater number of the titrations of samples from the deepest strata have given values corresponding to 34·93 and 34·94 ‰ of salinity.

According to these observations (if they are sufficiently correct) it thus seems as if the amount of chlorine in the bottom-water of the Norwegian Sea might vary less than its specific gravity. The determinations of the samples from Stats. 29 and 19 form strange exceptions, their salinities, obtained by Helland-Hansen's titrations being comparatively high (about 34·95 and 34·966 ‰; at Stat. 29, 1300 metres, it was 34·94 ‰). LEIVESTAD'S titrations also gave fairly high values at these stations, although not so high on the whole. The specific gravities, found for the same samples are also comparatively high (28·07, 28·075 and 28·085); and it thus seems probable that the cold bottom-waters at these stations have actually had compara-

(1) The standard water used for controlling the titrations had been made by Mr. SCHETELIG, and determined with the Hydrometer of Total Immersion [cf. NANSEN, 1906, p. 9].

(2) HELLAND-HANSEN'S samples, taken during the earlier part of the cruise, Stats. 7 (July 23) to 19 (August 7) had been kept a longer time, between four and five weeks, before the titrations were made at the end of August, 1900; and there is a greater possibility of evaporation through the corks in the case of these samples [cf. NANSEN, 1901, pp. 139—142].

Observations of Bottom-Water of the Norwegian Sea, July—Sept., 1900.

Station and *Date* 1900.	*Locality.*	*Depth* in *Metres.*	*Temp. in situ.* ° C.	*Hydrometer* of *Total Immersion.*		S °/oo by *Titration.*		Δ S—S'	σt (computed from σo)
				σo	S' °/oo	Helland-Hansen.	Leivestad.		
7		600	— 0·51			34·95			[28·120]
July 23,	63° 6' N.	700	— 0·92	28·065	34·925				·108
1900.	2° 46' E.	800	— 1·01	·066	·926				·112
		860	— 1·04	·065	·925	·94		+ 0·015	·112
		910	— 1·05	·08	·94		34·93	— 0·01	·127
8	63° 51' N.	600	0·17	·07	·93	·96		+ ·03	·061
July 24,	1° 14' W.	800	— 0·35	·065	·925				·082
1900.		1450	— 0·84	·065	·925	·94	·92	+ ·005	·105
9		400	0·31	·06	·92	·95		+ ·03	·043
	63° 53' N.	600	— 0·16	·04	·89	·92		+ ·03	·049
July 26,	6° 22' W.	800	— 0·54	·065	·925	[35·14]	·93	+ ·005	·091
1900.		1200	— 0·86	·055	·912	34·948	·94	+ ·032	·095
		1400	— 0·94	·05	·905	·948	·96	+ ·049	·096
9 A	63° 53' N.	1800	— 1·02	·05	·905	·94	·96	+ ·045	·097
July 27.	7° 24' W.	2030	— 1·04			·93			
		2100	— 1·05	·05	·905	·93	.94	+ ·03	·098
10	64° 53' N.	400	— 0·33	·05	·905	·94	·91	+ ·02	·066
July 28,	10° 0' W.	500	— 0·60	·053	·909	·94	·95	+ ·036	·082
1900.		600	— 0·68	·055	·912	[35·02]			·087
17	67° 28' N.	400	— 0·13	·05	·905	·957		+ ·05	·056
Aug. 5.	14° 30' W.								
18		600?	0·41	·065	·925	·957	·91	+ ·008	·042
Aug. 6,	69° 9' N.	1000	— 0·72	·065	·925	·966	·94	+ ·028	·099
1900.	12° 0' W.	1300	— 0·86	·06	·918	·957	.95	+ ·036	·101
		1500	— 0·95	·06	·918	·95	·95	+ ·032	·104
19	70° 35' N.	300	0·22	·07	·930	·95		+ ·02	·058
Aug. 7.	11° 10' W.	400	— 0·06	·07	·930	·966		+ ·036	·073
		600	— 0·45	·07	·930	·957	·94	+ ·013	·092

20 Aug. 7.	70° 47′ N. 10° 40′ W.	300	0·08	·06	·92	·966		+ ·046	·056
29 Aug. 9, 1900.	70° 46′ N. 6° 32′ W.	400	0·22	·07	·930	·966		+ ·036	·058
		600	— 0.31	·075	·936	·966	·95	+ ·022	·091
		800	— 0.51	·075	·936	·966	·94	+ ·017	·100
		1000	— 0.69	·075	·936	·948	·94	+ ·008	·108
		1300	— 0.84	·085	·95	·94	·945	— ·007	·124
		1530	— 0.97	·075	·936	·948	·94	+ ·008	·120
34 Aug. 10, 1900.	70° 15′ N. 2° 30′ W.	600	0·41	·09	·955	·966		+ ·011	·065
		800	— 0·32	·06	·918	·948	·96?	+ ·03	·077
		2000	— 1·10	·05	·905	·94	·92	+ ·025	·100
		2300	— 1·1	·05	·905	·93	·92	+ ·02	·100
		2800	— 1·1	·05	·905	·94	·905	+ ·017	·100
43 Aug. 11, 1900.	69° 52′ N. 5° 15′ E.	600	3·08	·19	35·08	35·08		·00	27·962
		1000	0·14	·08	34·942	34·94	·92	— ·012	28·072
		1100?	— 0·04	·08	·942		·93	— ·012	·081
		2000	— 0·94	·07	·930		·93	·00	·114
		3000	— 1·0?	·07	·930	·930	·92	— ·005	·118
46 Aug. 13, 1900.	69° 13′ N. 10° 40′ E.	800	1·60	·13	35·00	·99		— ·01	·028
		900	1·36	·11	34·98	·97		— ·01	·026
		1000	— 0·08	·08	·942	·94		— ·002	·084
		1500?	— 0·63	·07	·930				·100
		2000	— 0·94	·07	·930	·93		·00	·114
		3000	— 1·02?	[.14](1)	[35·02]		·930		·119
47 Aug. 14, 1900.	69° 55′ N. 13° 16′ E.	600	2·47	.16	35·04	35·047		+ ·007	27·988
		800	— 0·17	·07	34·930	34·930		·00	28·079
		1000	— 0·73	·07	·930	·94		+ ·01	·105
64 Sept. 6, 1900.	74° 12′ N. 11° 50′ E.	620	0·80	·10	·97	·97		·00	·053
		1040	— 0·65	·08	·94	·93	·96	+ ·005	·111
		2145	— 1·11	·055	·912	·94		+ ·028	·105
65 Sept. 6, 1900.	72° 56′ N. 13° 10′ E.	830	— 0·45	·06	·92	·93		+ ·01	·082
		1040	— 0·76	·08	·94	·93	·92	— ·015	·115
		1550	— 1·09	·08	·94	·93	·93	— ·01	·129
68 Sept. 8, 1900.	69° 37′ N. 11° 28′ E.	630	3·05	·19	35·08	35·08		·00	27·963
		845	1·25	·11	34·98	34·99		+ ·01	·032
		1045	— 0·05	·06	·92	·93	·92	+ ·005	·062
		2045	— 0·96	·06	·92	·94	·955	+ ·027	·104

Mean Δ = + 0·015

(1) The water-bottle had struck the bottom and there was much mud in the sample. The values of specific gravity obtained were therefore much too high.

tively high values of specific gravity and chlorine. There are moreover less difference between the values of salinity obtained in the two different ways. The samples of bottom-water from Stat. 18 show by titrations a similar tendency towards high salinities, while their specific gravities are somewhat lower (28·06 and 28·065).

If we assume that it is practically the same bottom-water, with very nearly the same origin, which fills the Norwegian Sea at all great depths, say greater than 1300 metres, the above observations would seem to indicate that, as a rule, this water keeps its amount of chlorine fairly constant, whereas its specific gravity is somehow changed during its circulation in the basin.

What the cause of these variations in the deep strata of the sea,—if they really exist and are not due to errors of observation,—might be, it is difficult to decide before special investigations have been made. It is possible for instance, that the amount of lime may vary. Where there is an abundant plankton life, with innumerable organisms forming calcareous shells at intermediate depths, the amount of lime in the sea-water may be somewhat reduced, while on the other hand the bottom-water at other places, especially at great depths, may have its amount of lime increased by lime dissolved from the bottom, or from shells sinking down from above. In this manner sligth variations may be caused in the specific gravity of the sea-water, and in the ratio between chlorine and specific gravity. This ratio may also be altered by variations in the ratio between the sulphates and chlorides of the sea-water, such as is produced when sea-water freezes at temperatures lower than —8° C. The freezing of the sea-water also influences the ratio between lime and the total amount of salt. Changes of this kind can naturally only take place near the sea-surface, but they may be of some importance for the composition of the salts of the cold sinking surface-water, forming the bottom-water. If the bottom-water be formed at the surface while ice is formed, especially at low temperatures (below —8° C.), one might expect that the sinking water would contain an amount of chlorine which is slightly greater than the normal. But if this water be formed in regions where much ice, previously exposed to low temperatures, has melted, or where the brine of such ice has been washed out, it is then possible that its amount of chlorine may be slightly smaller than normal, while it contains a slightly larger amount of sulphates and carbonate of lime than usual.

It is a striking fact in the above series of observations of the bottom-water of the Norwegian Sea, that the values of the salinities obtained by the titrations, not only those of LEIVESTAD, but also those of HELLAND-HANSEN, are on the average slightly higher than the salinities computed from the specific gravities, the mean difference being 0·015 ‰. It is, however, possible that these higher values given by the titrations might be due to the evaporation of water from the samples before the titrations were made (see above).

In order to make more accurate determinations of the bottom-water of the Norwegian Sea, we had a number of water-samples from the deeper strata, collected during the cruise in May and June, 1904. Unfortunately these samples were taken from no very great depths, the deepest sample being from only 1800 metres, and from no strata of bottom-water with very low temperatures. The greater number of samples were from 600 metres only, and the temperature *in situ* was in most cases above $-1°$ C. This collection of samples is not therefore quite comparable with those of the above table, taken in 1900.

All the samples were kept in old bottles (well washed by previous use) with patent india-rubber stoppers. The samples were examined at the International Central Laboratory in Christiania, during the autumn of 1904, and the winter of 1904—05.

The specific gravity (σ_0) was determined by Hydrostatic Weighings, by NANSEN, Dr. V. WALFRID EKMAN, and Mr. JAKOB SCHETELIG. Several hydrostatic weighings were made of each sample, especially numerous of those from the greater depths. Some samples were also repeatedly examined on different days. The mean values of each series of observations are given in the following Table.

The specific gravity of six samples were determined both by Nansen and by SCHETELIG, but the values of σ_0 obtained by the latter is, on the average, 0·007 higher. This is evidently due to the fact that SCHETELIG used *another* glass body (II) of immersion for his determinations. Nansen generally used glass body No. I, but on a few occasions he used the same glass body as SCHETELIG, and also obtained higher values. On two occasions EKMAN and Nansen made determinations of the same samples. In the one case (Stat. 21 A), when they both used the same glass body as SCHETELIG (No. II), the values obtained are almost identical (differing only 0·0006); while in the other case (Stat. 16 B) EKMAN's value is 0·011, lower than that of Nansen. On this occasion Nansen used glass body No. II while Ekman used No. I. The explanation is evidently that the volume of the two glass bodies has not been determined with equal accuracy. Judging from the values of the specific gravity obtained by the different determinations, we have received the impression that the glass body No. I, chiefly used by Nansen, has given the more correct values. These observations are marked with an *asterisk* in the sixth column of the following Table. The letters after the values in this column mean: S that the observations were made by SCHETELIG, E by EKMAN, and N by NANSEN.

After the hydrostic weighings had been made, the chlorine (halogen) of seven samples, of which a sufficiently large quantity remained, were determined by Dr. J. J. FOX by *Volhard's* method of titration.(1) The results of these determinations

(1) In a communication to us Dr. FOX states that the probable error of these analyses is between 0·002 and 0·005 ‰ Cl., or between 0·004 and 0·009 ‰ salinity.

Observations of Bottom-Water of the Norwegian Sea, May & June, 1904.

1 Station.	2 N. Latitude.	3 Longitude.	4 Depth in Metres.	5 t° C. *in situ.*	6 Hydrostatic Weighing. σ_0	7 S' ‰.	8 Titration. S ‰.	9 Cl ‰.	10 Δ S—S'.	11 σ_t (computed from σ_0).
5	62° 26′	1° 00′ W.	600	— 0·15	28·0805(S)	34·943				28·088
6	62° 43′	1° 47′ »	600	— 0·31	·0745(S)	·936				·090
8	63° 16′	3° 11′ »	600	— 0·18	·071 (S)	·931				·081
»			800	— 0·44	·075 (S)	·936				·097
»			1000	— 0·69	* ·0775(N)	·939	34·899 v ·921	19·318 v ·33	— 0·040 v — ·018	·111
63	63° 32′	4° 18′ »	600	— 0·14	* ·083 (N)	·946	·924 v ·903	·332 v ·32	— ·022 v — ·043	·091
43	64° 02′	5° 02′ »	600	0·08	·085 (S)	·949				·081
64	65° 09′	8° 04′ »	600	— 0·43	·079 (S)	·941	·921	·33	— ·020	·101
»			1250	— 0·90	* ·072 (N)	9·32	·895 v ·921	·316 v ·33	— ·037 v — ·011	·114
65	66° 07′	8° 51′ »	600	— 0·40	·077 (S)	·939	·928	·334	— ·011	·098
15	67° 27′	10° 10′ »	600	— 0·48	·080 (S) ·082 (E)	·944				·105
»			1000	— 0·79	·073 (N)	·933	·905 v ·903	·321 v ·32	— ·028 v — ·030	·111
			1500	— 0·96	* ·069 (N)	·929	·912 v ·921	·325 v ·33	— ·017 v — ·008	·113
16 B	67° 35′	12° 18′ »	600	— 0·53	·075 (S)	·936	·913	·326	— ·023	·101
»			800	— 0·72	·078 (S)	·940	·921	·330	— ·019	·113
»			1800	— 1.34	·069 (N) * ·058 (E)	·922	·921	·33	— ·001	·125
17 A	67° 48′	7° 39′ »	600	— 0·45	·074 (S)	·935	·895	·316	— ·040	·097
18 A	67° 48′	4° 54′ »	600	0·65	·084 (S)	·947				·045
19 A	67° 44′	2° 06′ »	600	0·36	* ·077 (N) ·082 (S)	·942	·939	·34	— ·003	·058
20 A	67° 40′	0° 12′ E.	600	0·46	·088 (S) ·087 (S)	·951	·930	·335	— ·021	·062
20 B	67° 30′	1° 55′ »	600	2·62	·107 (S)	·976				27·928
21 A	67° 21′	4° 07′ »	300	3·74	·140 (S)	35·014				·846
»			600	0·17	·084 (N) ·0834(E)	34·948	·957	·350(1)	+ ·009	·074
22	67° 12′	6° 22′ »	600	1·30	* ·102 (N)	·970	·924 v ·939	·332 v ·34	— ·046 v — ·031	28·021
			1200	— 1·00	·075 (S)	·936	·924	·332	— ·012	·121

(1) Hydrostatic Weighings had been performed 3 times with this sample before the chlorine determination.

1 Station.	2 N. Latitude.	3 Longitude.	4 Depth in Metres.	5 t° C. *in situ.*	6 Hydrostatic Weighing. σ_0	7 Hydrostatic Weighing. S ‰.	8 Titration. S' ‰.	9 Titration. Cl ‰.	10 Δ S—S'.	11 σ_t (computed from σ_0).
23 A	67° 07′	7° 50′ E.	600	— 0·53	28·082 (S)	34·945	34·912	19·325	— ·033	28·108
28 A	65° 16′	4° 26′ »	600	— 0·14	* ·078 (N) ·085 (S)	·944	·899	·318	— ·045	·089
»			1000	— 1·11	* ·067 (N)	·926	·930 v ·921	·335 v ·33	+ ·004 v — ·005	·117
29	65° 00′	2° 30′ »	600	0·13	* ·075 (N) ·077 (S)	·937	·924	·332	— ·012	·069
30	64° 49′	0° 37′ »	600	— 0·01	·086 (S)	·949	·915	·327	— ·034	·086
35	64° 53′	1° 20′ W.	600	— 0·12	·081 (S)	·944	·930	·335	— ·014	·088
36	64° 55′	2° 52′ »	600	0·02	[·222 (E)]					
»			1000	— 0·66	* ·072 (N) ·0754(N) [·084 (S)]	·934				·105
49	65° 01′	4° 32′ »	600	0·15	·086 (S)	·950	·930	·335	— ·020	·077
50	65° 04′	6° 06′ »	600	— 0·15	·080 (S)	·942	·914	·326	— ·028	·088
67	63° 58′	1° 56′ »	600	— 0·04	·085 (S)	·949	·906	·322	— ·043	·087
69	63° 42′	0° 56′ E.	600	0.30	·083 (S)	·945	.921	·330	— ·024	·065
70	63° 27′	1° 32′ »	600	0·10	* ·065 (N) ·078 (S) ·078 (S)	·935				·068
37	63° 12′	2° 06′ »	600	— 0.38	·086 (S)	·950	·921	·330	— ·029	·106
»			1000	— 1.09	* ·065 (N) [·072 (S)]	·924	·908	·323	— ·016	·115
								Mean:	— 0·022	

Observations of Deepest and Coldest Bottom-Water, May & June, 1904.

Station.	Depth in m.	t° C. *in situ.*	σ_0	S' ‰ by Hydr. Weigh.	S ‰ by Titration.	Δ S—S'.	σ_t (from σ_0).
16 B	1800	— 1·34	28·062(1)	34·920	34·921	+ 0·001	28·120
28 A	1000	— 1·11	·067	·926	·930 v ·921	+ ·004 v — ·005	·116
37	1000	— 1·09	·065	·924	·908	— ·016	·114
22	1200	— 1·00	·068	·928	·924	— ·004	·114
15	1500	— 0·96	·069	·929	·912 v ·921	— ·017 v — ·008	·112
64	1250	— 0·90	·072	·933	·895 v ·921	— ·038 v — ·012	·114
Mean according to the Mohr Titrations — 0·008							

(1) EKMAN'S determination of this sample was only made by a few weighings. We have therefore used Nansen's determinations with the glass body No II and reduced his value of σ_0 by 0·007.

are given in the 8th and 9th columns of the table (and are marked with a *v*). The values of salinity thus obtained are, with *only one exeption, remarkably* lower than those computed from the hydrostatic weighings. In order to have this striking difference further tested, the amount of chlorine in the same samples, as well as in a number of the other samples, was also determined by titration according to Mohr's method. The analyses were mostly made by Miss Dr. STEPHANSEN and a great many by Dr. FOX. Dr. FOX considers the values obtained by these titrations (given in the Table) to be very reliable; they are the means of from 3 to 5 concordant determinations. Of the four samples from Stats. 16B (600 and 800 metres), 17A (600 metres), and 23A (600 metres) a still larger number (5 or 6) of concordant determinations were made, and Dr. FOX believes that the mean values obtained are «absolutely correct to within $\pm$ 0·005 ‰ Cl.» (*i. e.* $\pm$ 0·009 ‰ salinity). Where no *v* is added to the values of the 8th and 9th column they have been obtained by this method.

It appears to us probable that the values of salinity thus obtained by Mohr's method are more accurate than those by Volhard's; but even the former, with *one* exception, are lower than those computed from the specific gravity.

The mean difference between the salinities obtained by titrations and those computed from the hydrostatic weighings is 0·027 ‰, when Volhard's method was used, and 0·021 ‰ when Mohrs method was used for the same samples. The mean difference off all observations is 0·022 ‰.

The titrations (both by HELLAND-HANSEN and by LEIVESTAD) of the samples of bottom-water from the cruise of 1900 gave, as a rule, higher salinities than the determinations of specific gravity. As it is hardly probable that this difference between the determinations of the samples from the two years is due to a difference in the composition of the samples themselves (ratio between Cl. and σ_0), we must conclude that either the titrations of the samples from July—Sept. 1900, have given comparatively higher values of *salinity* (about 0·03 ‰) than those obtained for the samples of May and June, 1904, or the determinations of the *specific gravities* of the former must have given comparatively lower values than those of the latter.

Let us first compare the specific gravities found for the two years. It is unfortunate that only five samples were taken from fairly deep strata with low temperatures (near $-1°$ C.) in 1904; and it is therefore hardly possible to make a trustworthy comparison between the samples of the two years, as the conditions are evidently more variable in the higher strata of the sea, about 600 metres, than in the deeper and colder strata.

We will take the values of σ_0 found by Nansen's determinations of the four coldest samples from 1904 (see second Table p. 337). The fifth sample from Stat. 22, 1200 metres, was determined by SCHETELIG. We have seen above that his values of σ_0 are on the average 0·007 higher than those of Nansen, and we will therefore reduce them by that amount. A sixth sample from 1250 (Stat. 64) metres may be added, but the temperature was here higher, and we also find greater difference between titration and hydrostatic weighing.

The three Stations 16 B, 15, and 64 are on the western side of the Norwegian Sea, east and north-east of Iceland, while Stats. 22, 28 A, and 37 are on ist eastern side, along the continental slope off the Norwegian coast. The mean difference between the two series of salinities at the first three stations is — 0·007 ‰ (or if Stat. 64 with a higher temperature be left out, — 0·004), and at the last three Stations — 0·008 ‰, which amount the salinities obtained by the Mohr Titrations are lower than those computed from σ_0. These observations consequently indicate no marked difference in the ratio between *Cl* and σ_0 in the bottom-water on the western and eastern side of the Norwegian Sea, as the examination of the samples from the summer of 1900 seemed to indicate.

In the following Table those observations of samples from 1900 have been chosen, which will best correspond to the above observations of 1904 as regards locality, depth, and temperature. The numbers of the stations of 1904 are printed in *italics*.

The observations of specific gravity (σ_0) from 1900 in this Table are on the whole somewhat lower than those from 1904, the mean difference between them being about 0·003 of σ_0. This is no greater difference than may be due to inaccuracy of determination.

The samples taken from the deepest strata with the lowest temperatures (about or below — 1° C.), in July—September, 1900, (see Table, p. 332) give, on the whole, very low values of σ_0 (generally about 28·05, 28·055, and 28·06). These values are lower than those found, even for the deepest and coldest water-samples in 1904; but the vertical series of observations from both years indicate that the specific gravity of the bottom-water has a tendency to decrease slightly with increasing depth and falling temperature [cf. HELLAND-HANSEN and KOEFOED, 1909]. The values of σ_0 for the great depths examined in 1900, may therefore be expected to be comparatively low, although the values of 28·05 seem to be somewhat too low.

The salinities of the bottom-water obtained by titration are in all cases *higher* in the samples from 1900 than in those from 1904. If the means of all titrations, made by HELLAND-HANSEN and LEIVESTAD, for each station of 1900, given in the above Table (p. 332), be compared with those for the corresponding stations of 1904, we find a mean difference of 0·029 ‰. It is hardly possible that this great difference can be due to variations in the actual salinity of the bottom-water of the two years, *Comparisons between Observations of Cold Bottom-Water taken in 1900 and 1904.*

Stations.	Depth in Metres.	t° C. *in situ.*	σo	S' ‰.	Titrations S ‰ Helland-Hansen and Fox.	Titrations S ‰ Leivestad.	Mean Δ S—S'.
7 (a little south-east of *37*).	800	— 1·01	28·066	34·925	34·94		+ 0·007
	860	— 1·04	·065	·924	·94		
	910	— 1·05	·08	·94		34·93	
37	1000	— 1·09	·065	·924	·908		— 0·017
Mean difference between *37* and 7			— 0·005	— 0·006	— 0·029		
8 (north of *8*).	800	— 0·35	28·065	34·925			+ ·005
	1450	— 0·84	·065	·925	34·94	·92	
8	800	— 0·44	·068	·928			— ·023
	1000	— 0·69	·0775	·939	·910		
Mean differance between *8* and 8			+ 0.008	+ 0·009	— 0·020		
9 and 9 A (between *8* and *64*).	800	— 0·54	28·065	34·925		·93	+ ·011
	1200	— 0·86	·055	·912	34·95	·94	
64	1250	— 0·90	·072	·932	·921		— ·011
Mean difference between *64* and 9 & 9 A			+ 0·012	+ 0·013	— 0·029		
18 (north of *16 B* and *15*).	1000	— 0·72	28·065	34·925	34·965	·94	+ ·033
	1300	— 0·86	·06	·918	.96	·95	
	1500	— 0.95	·06	·918	·95	·95	
16 B	1800	— 1·34	·062	·920	·921		— ·004
15	1500	— 0.96	·069	·929	·921		
Mean difference between last two and 18			+ 0·004	+ 0·005	— 0·037		
43 (far north of *22*).	2000	— 0·94	28·07	34.93		·93	+ ·003
	3000	— 1·00	·07	·93	·93	·92	
46 (far north of *22*).	1500?	— 0·62	·07	·93		·95	
	2000	— 0·92	·07	·93	·93	·95?	
47 (far north of *22*).	1000	— 0·73	·07	·93	·94		
22	1200	— 1.00	·068	·928	·924		— ·004
Mean difference between *22* and other three			— 0·002	— 0·002	— 0·009		

considering that the salinities computed from the specific gravities of the same samples are on the average 0·004 ‰ *lower* in 1900 than in 1904.

The titrations of the above Table (p. 340) gave in 1900 on the average 0·012 ‰ *higher* values of salinity than those computed from σ_0(1), while for the samples from 1904 the corresponding mean difference was 0 012 ‰ in the opposite direction, the titrations giving *lower* values (cf. Table, p. 340).

It is consequently probable that the striking disagreement between the salinities of the bottom-water found by titrations for the two years, must be due to some kind of difference in the observations.

It is hardly possible that it can be explained by any appreciable inaccuracies in the determinations of the salinity of the Standard Waters used by the several observers, as there is good reason to assume that these Standard Waters were very trustworthy,(2) especially those used by HELLAND-HANSEN, and by Dr. FOX and Miss Dr. STEPHANSEN.

The cause of the disagreement between the salinities of the two years must, according to our view, at least to some extent be that the water-samples of 1900 have given somewhat too high values of chlorine owing to evaporation of water from the samples before they were examined by titration. Helland-Hansen's samples were small, only 100 cub. cm., and were kept in glass bottles with cork stoppers (see above, p. 60) through wich there must always have been some slight evaporation, especially when the samples remained in the bottles for some time before the titrations were made [cf. NANSEN, 1901, pp. 141—142, & Pl. 3]. In some cases the errors thus produced were considerable (cf. above pp. 60—62). The probability of this ex-

(1) This mean difference was 0·015 ‰ for all determinations of the samples of bottom-water taken in 1900, see Table, p. 332.

(2) HELLAND-HANSEN used Standard Water that he had received from Mr. MARTIN KNUDSEN in Copenhagen. It was the same Standard Water that was used for the determinations of Constants forming the basis of Knudsen's Tables. The possibility that there can have been any appreciable error in the value of the chlorine in this Standard Water is thus excluded. When Nansen wrote his preliminary report [1901] the amount of chlorine in this Standard Water had not yet been accurately computed. The salinities given in Nansen's paper are therefore not quite accurate.

The Standard Water used by LEIVESTAD had been made by Mr. SCHETELIG by mixing several samples of sea-water [cf. Nansen's description, 1906, pp. 9—10]. As the value of its chloiine was computed exclusively from its specific gravity, determined by means of the Hydrometer of Total Immersion, there is a possibility that this value may not have been quite accurate. But it was the same Standard Water LEIVESTAD used for the titrations of AMUNDSEN'S cold Bottom-Water from the sea north of Jan Mayen (AMUNDSEN'S Stats. 13—23); and the salinities he has thus obtained for this water, cannot, at any rate appreciably, be too high; they vary between 34·88 and 34·93 ‰ and chiefly between 34·90 and 34·92, [cf. NANSEN, 1906, pp. 141—144); and on the whole they seem to be very accurate.

The Standard Water used for Dr. FOX'S and Miss Dr. STEPHANSEN'S titrations was of the regular stock made at the International Central Laboratory in Christiania. Its σ_0 had been determined by Dr. EKMAN, and its chlorine by Dr. FOX himself. There is no probability that an error, approaching the amount of the discrepancy found above, should have occurred in these determinations.

planation is proved by the fact that Helland-Hansen's values of salinity are especially high in proportion to σ_0 for all samples from the beginning of the cruise of 1900 (from July and the beginning of August) as is seen in the Table, p. 332. In the following Table are given the mean differences between the salinities of the Bottom-Water (cf. Table p. 332) obtained by Helland-Hansen's titrations, and those computed from σ_0 for the various parts of the cruise.

Date when Samples were taken.	Mean Difference between Salinities computed from σ_0 and those obtained by Helland-Hansen's Titrations.
July 23—28, 1900	0·050 ‰
August 5—7, »	·036 »
» 9—10, »	·024 »
» 11, »	·000 »
» 13—14, »	— ·001 »
September 6—8, »	·005 »

This Table shows that while the salinities obtained by titration were as much as 0·05 ‰ higher than those computed from σ_0 for the samples from the beginning of the cruise, July 23—28 (when about five weeks elapsed between the taking and the titration of the samples), this difference decreases gradually until it is $\pm$ 0·0 for the samples taken on August 11th, and — 0·001 ‰ (*i. e.* the salinities by titration were *slightly lower than those computed from* σ_0) for those of August 13 & 14. The titrations were made about three weeks after August 14th. For the samples of September 6—8, the difference is again somewhat higher (0·005 ‰).

We can hardly expect a closer agreement, considering that the specific gravities of the samples were determined with no greater accuracy than one unit of the fifth decimal place (*i. e.* the second decimal place of σ_0).

According to what was explained above (p. 331) it is to be expected that LEIVESTAD'S titrations of the water-samples of 1900, would also give somewhat too high values of salinity although, on the whole, not so much so as Helland-Hansen's for the first part of the cruise. LEIVESTAD'S salinities of the bottom water (see Table, p. 332) are on the average 0·010 ‰ higher than those computed from σ_0.

As the above table shows, Helland-Hansen's titrations of the samples of bottom-water give salinities which on the average agree almost perfectly with those computed from σ_0, when his titrations were made a short time (about three weeks) after the water-samples had been bottled. Where this interval was shortest (for samples of Aug. 13 & 14, 1900) his values even had a tendency to be slightly lower. But if a slow evaporation is always taking place through the corks,(1) we are obliged

(1) The cork stoppers are more or less hygroscopic, and will therefore always absorb some moisture from the enclosed water-sample, whereby the salinity will be slightly increased.

to assume that even in this most favourable case, his values of salinity have become a trifle too high; and we must consequently conclude that if his titrations had been made immediately after the water-samples had been taken, he would have found salinities that would have been on the average slightly lower than those computed from σ_0 by KNUDSEN's Tables. This agrees with what we have found above from Dr. FOX's and Miss Dr. STEPHANSEN's determinations of the chlorine in the samples of bottom-water of 1904; although the differences given by their titrations are decidedly greater, and certainly somewhat too great.

Our many and various observations seem thus to indicate that the amount of *Chlorine* in the cold bottom-water of the Norwegian Sea is slightly *lower* in proportion to σ_0 than it should be according to KNUDSEN's Tables and formula. According to Dr. FOX's determinations, this deficiency of chlorine is not constant, but varies somewhat irregularly. This has, however, to be verified by more complete future investigations. Our present observations indicate, at any rate, that the deficiency of chlorine is very small in the case of all samples taken in 1904 from the deepest strata (1000—1800 metres) with low temperatures (near —1° C.), the salinities computed from the chlorine being on the average only 0·008 ‰ lower than those computed from σ_0.(1)

It may be of some interest here to draw attention to the determinations of chlorine and specific gravity of several series of water-samples from the Barents Sea and the sea north of Jan Mayen mentioned in Nansen's paper, "Northern Waters" [1906, pp. 10 & 11, 40, 44, 51], as some of them show greater variations in the ratio between Cl and σ_0 than can probably be explained by errors of observation. While in the surface-strata, between 1 and 40 metres, at AMUNDSEN's Stat. 22 *a*, in the sea north of Jan Mayen, the ratio between *Cl* and σ_0 was (with the exception of the surface-water) normal according to KNUDSEN's Tables; the samples from the water-strata at the same depths (1—40 metres) at AMUNDSEN's Stat. 6 *a*, in the Barents Sea, had, according to the titrations by the same observer (LEIVESTAD), a relatively too high amount of chlorine, giving salinities which are on the average 0·026 higher than those computed from σ_0.

At MAKAROFF's Stats. 77, 78, and 82 between Novaya Semlya and Franz Josef Land [see NANSEN, 1906, p. 51] the titrations gave appreciably higher salinities than those computed from σ_0 for samples from the surface and the upper water-strata; while for the deepest strata (down to 300 metres) they gave salinities that were slightly too low. But the salinities obtained by titrations of samples from the

(1) See *Postscript* to this chapter.

still deeper but warmer strata (down to 350 metres) at Stat. 83, are again relatively too high.

The water-samples from the very cold (— 1·8 ° C.) water-strata between 1 and 150 metres at MAKAROFF's Stat. 57, west of Novaya Semlya [cf. NANSEN, 1906, p. 44] show a fairly close agreement between the salinities obtained by titration and those computed from σ_0, the former having a tendency to be slightly higher, on the average only 0·004 ‰.

The samples from WOLLEBÆK's Stat. II west of Novaya Semlya [see NANSEN, 1906, p. 40] had on the whole a comparative dificiency of chlorine, the titrations giving, on the average, salinities *lower* by 0·008 ‰ than those computed from σ_0. At this station the salinities were nearly uniform and high, from the surface to the bottom, while the temperatures were low, indicating that there had recently been an active vertical circulation forming bottom-water. It is perhaps noteworthy that the titration of the sample from 10 metres gave a *higher* (0·01 ‰) salinity than the specific gravity, while for the underlying strata the salinities found by titration were on the average 0·011 ‰ *lower* than those computed from σ_0. It is also a noteworthy coincidence, which may not be accidental, that both at this station and at MAKAROFF's above-mentioned Stat. 57, the titrations of the very cold (— 1·8 ° C.) and heavy water-stratum near the bottom, gave salinities that are lower than those computed from σ_0, and more so than those of the overlying strata.

The various series of observations mentioned above may perhaps indicate that there are certain small variations in the ratio between Chlorine and Specific Gravity in the Northern Seas, but the observations are too few and too accidental, and are not sufficiently accurate to enable us to draw any trustworthy conclusions in this respect. As we have pointed out above (p. 334) [cf. also NANSEN, 1906, pp. 10 & 11] there is a possibility that the formation and melting of ice in these regions may cause variations in the composition of the sea-water, which may influence the ratio between Cl and σ_0 sufficiently to be noticeable in our determinations.

During the *Belgica* Expedition, of 1905, there were taken 39 samples of the bottom-water of the Greenland Sea (at Stats. 15—26, and 48—50) with temperatures below 0° C. and from depths greater than 500 metres. The mean value of chlorine, resulting from the very careful titrations of all these samples was 19·330 ‰, which gives S ‰ = 34·921 and σ_0 = 28·062.

Nine of the *Belgica* samples were taken from strata (at 1200 and 1800 metres) with temperatures below — 1·00° C. Their mean values were:

$$Cl = 19{\cdot}327\ ‰;\ S\ ‰ = 34{\cdot}915\ ‰;\ \sigma_0 = 28{\cdot}058.$$

Their mean temperature was — 1·10° C.

At AMUNDSEN's Stations 13—24, of June and July, 1901, [cf. NANSEN, 1906, pp. 141—144], 33 samples were taken from depths below the level of 500 metres (all of them with temperatures below $-1{\cdot}0°$ C.). The mean values found for these 33 samples are:

$$Cl = 19{\cdot}3245\ {}^0/_{00};\ S\ {}^0/_{00} = 34{\cdot}911;\ \sigma_0 = 28{\cdot}054.$$

Their mean temperature was $-1{\cdot}23°$ C.

The five samples of the coldest bottom-water of May & June 1904, with temperatures from $-0{\cdot}96°$ C. to $-1{\cdot}34°$ C., gave, according to the Table on p. 337, the following mean values:

$$Cl = 19{\cdot}329\ {}^0/_0;\ S\ {}^0/_{00}\ \text{(by titration)} = 34{\cdot}919;\ \sigma_0 = 28{\cdot}066;$$
$$\sigma_0\ \text{(by titration)} = 28{\cdot}061.$$
$$\text{Mean } t = -1{\cdot}09°\ \text{C.}$$

These determinations of the coldest bottom-water of the three different years (1901, 1904, and 1905) from different regions of the Norwegian Sea, agree remarkably well. They seem to indicate that the salinity of the bottom-water decreases sligthly with the temperature. Considering only the values obtained by titration we find the following salinities:

Year	1904	1905	1901
Mean t° C.	—1·09	—1·10	—1·23
Mean S ‰	34·919	34·915	34·911

The samples of the cold bottom-water of 1900 (Table p. 332) were not so accurately determined. The determinations with the Hydrometer of Total Immersion seem to be most trustworthy (cf. above p. 330). The mean value of the determinations of 42 samples with temperatures below 0° C. and from depths below the level of 600 metres was:

$$\sigma_0 = 28{\cdot}065;\ S\ {}^0/_{00}\ \text{(computed from } \sigma_0) = 34{\cdot}924.$$

This is a somewhat higher value of S ‰ than the above values of the coldest bottom-water of 1904, 1905, and 1901. We found, however, above that the mean value of the 39 samples of bottom-water with t lower than 0° C. of the *Belgica* Expedition, was, S ‰ = 34·921.

The determinations of the different years seem thus to agree very well; and we may assume that they are on the whole fairly

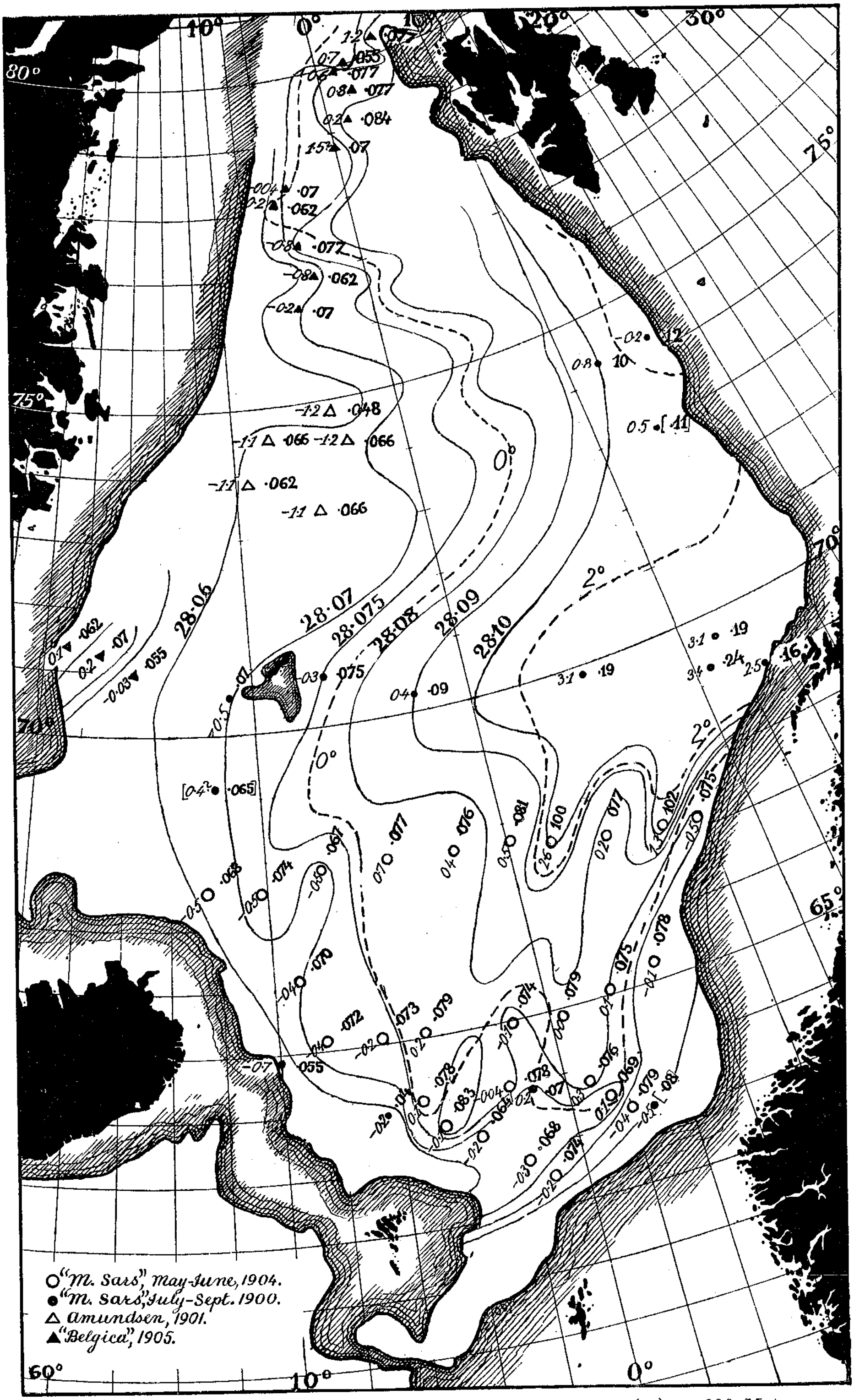

Fig. 110. Distribution of Temperature and Specific Gravity (σ_0) at 600 Metres.

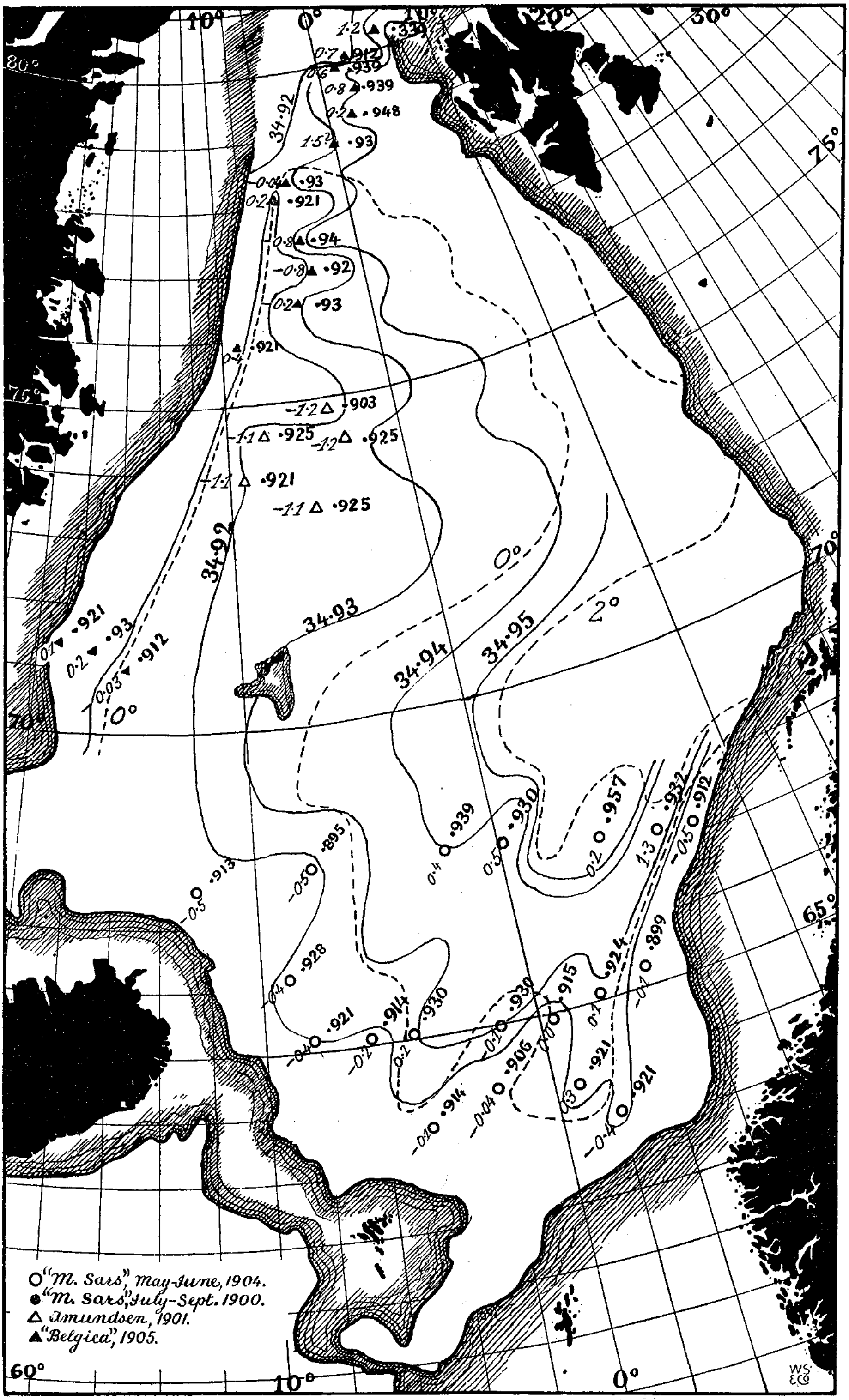

Fig. 111. Distribution of Temperature and Salinity at 600 Metres.

accurate. They seem to indicate that the variations in σ_0 and S ‰ of the bottom-water of the Norwegian Sea are very slight.

In the chart, Fig. 110, for 600 metres, the determinations of the specific gravity (σ_0) of all samples from 600 metres from the cruises of May & June, 1904, and July-Sept., 1900, have been introduced. The values of the hydrostatic weighings by Mr. SCHETELIG of samples from 1904 have been reduced by 0·007 (see above). For the purpose of comparison, the values of σ_0 at 600 metres at AMUNDSEN's Stations in 1901, north of Jan Mayen, have been added, the values having been computed directly from LEIVESTAD's titrations. We have also added the values of σ_0 computed from *Cl* at the *Belgica* stations of 1905 (600 metres). The observations from the four different years are not altogether comparable, not having been made with an equal degree of accuracy, and the methods employed having been different. But if we nevertheless attempt to draw the isopyknals(1) for σ_0 for the intervals of 28·06 (= 34·918 ‰), 28·07 (= 34·93 ‰), 28·075 (= 34·937 ‰), 28·08 (= 34·943 ‰), 28·09 (= 34·955 ‰), and 28·10 (= 34·967 ‰), we obtain a fairly probable picture, and the different observations seem to agree on the whole fairly well, and may indicate a certain regularity in the horizontal distribution of the specific gravity (or salinity). If we make a similar chart, Fig. 111, of the salinities obtained by Dr. FOX's and Miss Dr. STEPHANSEN's titrations of the samples from 600 metres, of May & June, 1904, and draw the isohalines for 34·92, 34·93, 34·94, and 34·95 ‰, we get a somewhat similar picture of the horizontal distribution of salinity at 600 metres, although, as we have seen above, the values obtained by the *titrations* are on the whole lower than those computed from σ_0. It is a striking fact that in both charts (of σ_0 and salinity) the isopyknals(1) and the isohalines follow approximately the same course as the isotherms. This seems to indicate that the observations are fairly correct. The lowest values of σ_0, as well as salinity computed from *Cl*, at the level of 600 metres, occur along the western, south-western, and southern side of the sea basin, while the highest values at this level occur in its eastern and north-eastern part.

(1) The word isopyknal means here the lines for equal specific gravity (σ_0), not density *in situ* (σ_t).

There are several bends or tongues in the isopyknals for 28·07 and 28·075, which may to some extent be due to inaccuracies of observation. The tongue of the isopyknal of 28·075 at Stat. 35 (1904), for instance, does not coincide with the similar tongue of the isohaline for 34·92 $^0/_{00}$ (Fig. 111), which is farther east, at Stat. 30, where σ_0 is especially high (28·081); this does not seem to agree well, but nevertheless, the isotherm of 0° C. forms a similar tongue in this region. On the whole, there is, for instance, a remarkable similarity in the shapes of the isopyknals for 28·07 and 28·075 to those of the isohaline of 34·90 $^0/_{00}$ on the charts for 400 metres and also 300 metres for May, 1904, Pl. XII, (see also for May, 1903, Pl. IX).

It seems therefore probable that the cold water with comparatively low σ_0 (and low salinity computed from *Cl* $^0/_{00}$) along the Iceland-Færoe Ridge, and eastwards near the Norwegian coast, may have some connection with the tongue of water with salinities below 34·90 $^0/_{00}$ (determined by titrations), extending south-eastwards from Iceland, at depths between 200 and 400 metres (see above pp. 293—296).

A study of the sections from the different years (Pls. XIV—XXIV) may lead to the same conclusion; it seems as if the titrations have often given comparatively low values at 600 metres in the neigbourhood of this tongue of less saline water. At Station 17 A, May, 1904, for instance, the water-sample from 600 metres gave comparatively low values of σ_0 (28·067(1) = 34·926 $^0/_{00}$) as also of salinity by titration (34·895 $^0/_{00}$). The section in Fig. 4 (Pl. XXIV A) shows that near this station the top layer of water with salinity below 34·90 $^0/_{00}$ (by titration) probably forms a tongue downwards, and the titrations of HELLAND-HANSEN(2) (made in Bergen, quite independently of the determinations in Christiania of the sample from 600 metres) give salinities of about 34·90 $^0/_{00}$ for all overlying strata between 150 and 500 metres, while the salinities found for the same strata are much higher both east and west of this station. The *densities* at Stat. 17 A are also lower than on both sides. Whether this lower salinity at the deeper strata, may have been caused by intermixture with the overlying less saline water-strata, it is difficult to decide in this case, as the temperatures give no certain indication. It would be necessary to know more about the condition in the sea from which this water comes.

According to our view, this and similar cases seem, however, to indicate that these water-strata between the top layers and 600 metres move more or less in the same direction, and that there is a flow of a volume of this kind of water, at least 600 metres deep, south-eastwards along the Iceland-Færoe Ridge, into the southern Norwegian Basin.

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(1) Determination by SCHETELIG, and reduced by 0·007.

(2) It is noteworthy that all the samples for titration of this cruise were taken in the small bottles with patent india-rubber stoppers, supplied through the Central Laboratory at Christianin. The possibility of the values of chlorine being too high, owing to the evaporation of water through the stoppers, is therefore excluded.

At Stat. 16 B (Fig. 4, Pl, XXIV A) the sample from 600 metres (see Table p. 336) gave comparatively low σ_0 (28·068 which has been reduced by — 0·007) and low salinity by titration (34·913 $^0/_{00}$).(1) The overlying strata also have low salinities, of 34·90 and 34·91 $^0/_{00}$, while at Stat. 15, east of Stat. 16 B, the salinities are considerably higher (34·94 and 34·93 $^0/_{00}$) at the depths between 200 and 600 metres. At Stat. 64 there are similarly low salinities (34·91 and 34·89 $^0/_{00}$) at all depths between 300 and 500 metres (see Fig. 3, Pl. XXIV A) and at 600 metres the salinity found by titration (see Table, p. 336) is also fairly low (34·92 $^0/_{00}$).(2) Some trace of this flow of less saline water may perhaps still be seen at Stat. 70, 1904, at 600 metres (see Fig. 2, Pl. XXIV A), where the specific gravity found ($\sigma_0 = 28{\cdot}069$)(3) is lower than at the same level at the stations on both sides (28·079 and 28·076). The nearest observation above 600 metres at Stat. 70, is at 400 metres, and shows the occurrence of the water with the typical low salinity of 34·88 $^0/_{00}$, while the salinities at the stations on both sides are considerably higher.

Besides these apparently fairly regular variations in the horizontal distribution of salinity at 600 metres, there is also seen in the sections another kind of variation, which is due to the apparently irregular "waves", which the isohalines, as well as isotherms and isopyknals, form in the sections (see above, pp. 89 *et seq.*). It may for instance be noticed that on the whole where the isotherm of 0° C. forms a wave upwards and rises above 600 metres, we there find as a rule a comparatively low salinity of the water, the less saline cold bottom-water seeming here to have been raised to higher levels than at other places. The section (Fig. 4, Pl. XXIV A) off Lofoten for May & June, 1904, is a very elucidating example. At Stats. 22, 20 B, and 18 A, the overlying strata with higher temperatures and high salinities form very deep "waves"; and at 600 metres both the salinities (and σ_0), and the temperatures are therefore higher than at the intervening stations.

The fairly accurate determinations of the specific gravity and salinity of the coldest bottom-water from depths greater than 600 metres are too few to give in any way a trustworthy representation of the horizontal distribution of σ_0 and salinity in the deepest part of the Norwegian Sea. In Fig. 112 we have, nevertheless, made an attempt. We have used the observations of May & June, 1904, for depths of 1000 metres or more, with temperatures lower than —0·6° C., or chiefly about —1° C. We have also used the observations of the coldest bottom-water from July– Sept., 1900. The values of temperature

(1) The salinities for 600 metres introduced in the Sections of Pl. XXIV A are computed from σ_0 without any reduction, while those for all depths between 500 metres and the surface are found by titration.

(2) The salinity (34·914 $^0/_{00}$) found by titration for 600 metres at Stat. 50 (see Table, p. 337) is evidently too low, as may be seen by comparison with the salinities of the overlying strata.

(3) This value is the mean of all three observations in the table on p. 337, after SCHETELIG's values have been reduced by 0·007.

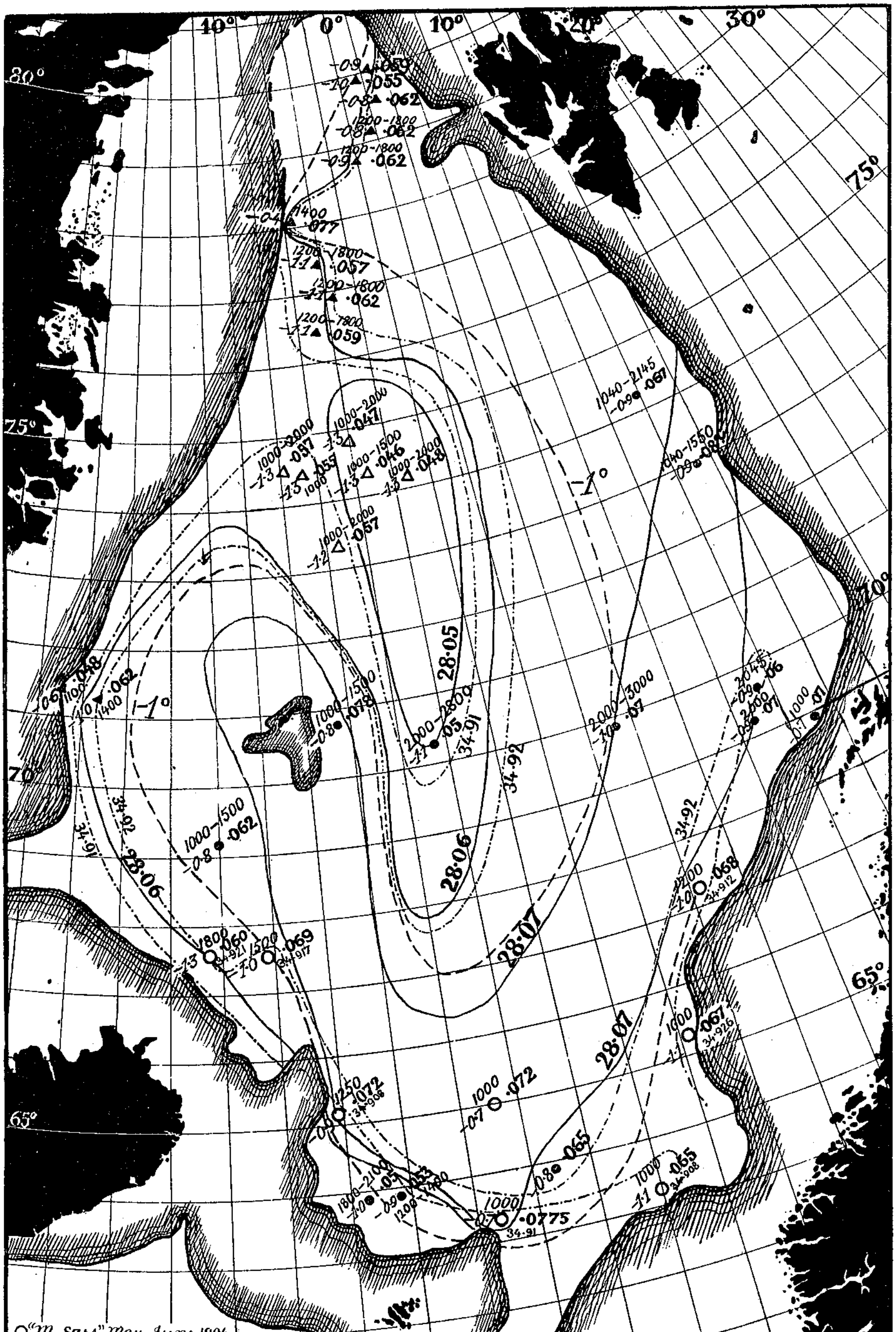

Fig. 112. Distribution of Temperature and Specific Gravity (and Salinity) at 1000 Metres and deeper levels.

and σ_0 given in the chart are, in the case of most stations, the means of all observations taken at different depths of cold bottom-water, with temperatures below —0·6 or —0·7° C (*cf.* Table p. 332). The depths (in metres) from which the observations were taken, are given on the chart, at each station. The means of the observations at AMUNDSEN's Stations 13—23 (1901), north of Jan Mayen, and at the *Belgica* Stations 15—26, 48 and 49 (1905), are also added, although the values of σ_0 are based on titrations. The means are taken of all observations at each station at depths of between 1000 and 2000 metres.(1).

This collection of obervations from different years is consequently somewhat heterogeneous, and trustworthy conclusions can hardly be based upon it. By drawing the isopyknals for 28·05, 28·06, and 28·07 we obtain, however, a picture which is somewhat peculiar and rather interesting. But it has to be considesed that the samples were taken from very different depths and had different temperatures.

In the northern part of the Norwegian Sea, east and north-east of Jan Mayen, there is a central area where the cold bottom-water has very low specific gravity ($\sigma_0 < 28·05$, or salinity below 34·91 ‰) and a low temperature (—1·3° C.). But as these values of σ_0 are chiefly based upon LEIVESTAD's titrations of AMUNDSEN's samples, and upon the one Station 34 of Aug., 1900, it is possible that they should have been somewhat higher, although probable not much. We have found above (p. 339) that the bottom-water with the lowest temperature seems to have the lowest σ_0; and if this be correct AMUNDSEN's samples ought to have very low σ_0. The observations at AMUNDSEN's several stations, and those at Stats. 29, 34, and 43 of August, 1900, all point to the same central region with low salinity (and low σ_0) of the cold bottom-water. There is also good agreement between AMUNDSEN's observations and the observations at

(1) The determinations of the salinity of the deep strata at the Danish stations north of the Færoes, and at the Scottish stations in the Færoe-Shetland Channel cannot be used for this purpose, as they are evidently not sufficiently accurate. In May, 1904, all the Scottish observations of the deep strata gave S ‰ = 34·96 ‰ ($\sigma_0 = 28·094$) and the Danish S ‰ = 34·94 and 34·95 ‰, while in previous seasons the values found varied between 34·87 ‰ (Sc.) and 35·05 ‰ (Da.).

the *Belgica* stations to the north. The actual existence of this central zone seems therefore probable.

Along the western, south-western, and southern side-slope of the Norwegian Basin, the observations indicate a narrow zone where the bottom-water has a low specific gravity (σ_0 below 28·07 and 28·065), and low temperature (below — 1·0° C.). The existence of this zone is perhaps also indicated by the titrations of Dr. Fox and Miss Dr. Stephansen (cf. the isohalines for 34·92 and 34·91 ‰).(1) If correct, this zone is of almost exactly the same extent and form as the zone of water with σ_0 below 28·07 at 600 m. (see Fig. 111). But the explanation is probably different, namely that the coldest water, with lowest σ_0, follows the bottom and consequently rises to higher levels near the side-slopes of the basin (cf. Sections, Pl. XXV). It is also striking in Fig. 112, how closely the isopyknals (of 28·06 and 28·07) and the isohalines follow the course of the isotherm of — 1° C. The observations farther away from the side-slopes have evidently not reached down into the cold layers of bottom-water with the lowest salinity, and with temperature below — 1° C.

As the observations of the cold bottom-water are very few and not sufficiently accurate, it is impossible to draw any certain conclusion from the above, as to its *circulation* at depths below 1000 metres in the Norwegian Sea. It would be necessary to collect a far greater number of perfectly trustworthy and accurate observations of Temperature (by the modern Richter Reversing Thermometers), Specific Gravity, and Chlorine from many different depths in the various regions of this sea. It would, for instance, be especially desirable to know more about the sea between Jan Mayen and Greenland; and it would also be necessary to know a great deal more about the deep strata in the central part of the sea between Jan Mayen, Iceland, and Norway, and also in the sea off Bear Island and Spitsbergen, etc. etc.

The greater part of the coldest bottom-water with temperatures about or below — 1° C. is formed in the sea north and north-east of Jan Mayen. It is possible that some part of this cold bottom-water, with comparatively low salinity, moves,

(1) The values of salinity found by Dr. Fox's and Miss Stephansen's titrations are given in small figures under the stations of 1904. The isohalines of 34 91 ‰ and 34·92 ‰ are drawn according to these values and the salinities found by titration at Amundsens Stations and the Belgica Stations.

under the Polar Current, southwards along the continental slope off Greenland, and possibly across the area between Jan Mayen and Iceland. The cold bottom-water with low salinity along the northern slope of the Færoe-Iceland Ridge and the slope off Norway, as seen in Fig. 112, may possibly be an updrift, however, along the slope of the bottom, from the bottom-water which forms the deepest strata in the central region of the basin. If, for instance, these cold bottom-strata along the sides of the basin move with a somewhat greater velocity than the overlying strata, they will naturally be raised to somewhat higher levels along the side slopes. It seems probable that the greater part of this coldest bottom-water comes southwards somewhere east of Jan Mayen, from the northern region where it is chiefly formed. But as pointed out above, these speculations on the horizontal circulation of the bottom-water of the Norwegian Sea are based on such a meagre and defective material in the way of observations, that they cannot be of much value.

As the deepest strata of the bottom-water which have the lowest temperatures, seem to have the lowest salinities (and σ_0), approaching in value those of the deep layers at AMUNDSEN's stations, it is probable that the increase in temperature of the bottom-water is chiefly due to intermixture with the overlying warmer and more saline water-strata, in which manner the coldest bottom-water gradually acquires a higher temperature and at the same time a slightly higher salinity.

Some heating of the bottom-water is certainly also caused by the interior heat of the Earth, through the contact with the sea bottom; but the conduction is very slow, and the quantity of heat thus received is very small [cf. NANSEN 1902, 1906].

Summary. Before we leave the bottom-water of the Norwegian Sea, we shall try to summarize our view of its nature and origin. Its *temperature* is low; being, in the deepest strata, between — 1·0° C. and — 1·3° C. (in very rare instances slightly below this, approaching — 1·4° C.), and rising slowly upwards towards the higher strata. Its *Specific Gravity, i. e.* σ_0, varies in the coldest bottom-water probably between 28·05 or 28·06 and 28·07. In higher strata with temperature rising towards 0° C., the specific gravity may be higher, but will hardly exceed 28·08 (= 34·94 ‰ salinity). The amount of *Chlorine* contained in the bottom.water seems, perhaps, to be slightly lower in proportion to the specific gravity, than it should be according to MARTIN KNUDSEN's formula; but according to our far too few determinations, this deficiency of chlorine varies and may possibly be somewhat smaller in the coldest and deepest strata of the bottom-water, (where it is, on the average, only about $-0.004\,^0/_{00}$ *Cl.*) than in the higher, somewhat warmer strata at 600 metres (the mean difference of all observations is about $-0.012\,^0/_{00}$ *Cl.*). The amount of chlorine in the cold bottom-water may possibly vary between 19·315 or 19·320 $^0/_{00}$ and 19·335 $^0/_{00}$ *Cl.* (equal to 34·90 and 34·930 $^0/_{00}$ salinity according to KNUDSEN's formula).

The coldest bottom-water of the Norwegian Sea is formed by the cooling of the sea-surface, towards the freezing-point of the sea-water, during the winter and spring, and by the formation of ice on the sea-surface, by which process the salinity of the cold surface-water is increased sufficiently to give it a density equal to, or slightly greater than, that of the bottom-water. The formation of the bottom-water in this manner takes place in the sea outside the eastern margin of the East Greenland Polar Current, chiefly in the sea between Jan Mayen and Spitsbergen, and possibly to some small extent between Jan Mayen and Iceland. The longer the formation of the cold, sinking surface-water lasts in a certain region, the heavier will the bottom-water formed become. The sinking surface-water first formed will not be heavy enough to reach the deepest layers of bottom-water, but will only sink to some less deep level; but as the underlying intermediate strata gradually become heavier as the vertical circulation reaches deeper and deeper, the cold surface-water will acquire a higher density, and may possibly at last become heavy enough to sink to the bottom, and form the deepest water-strata.

The surface-water forming the bottom-water is originally formed by an intermixture of cooled Atlantic water partly with water from the Polar Current, and partly with melting water from the ice melted in these regions during the summer. This ice was to a great extent formed in the same region during the previous winter. The higher strata of bottom-water, with temperatures between 0° C. and -1° C., may either be formed directly on the surface, in regions where the cooling of the water has not reached the lowest temperatures, or it may be formed by a gradual intermixture of the colder bottom-water with overlying warmer water with higher salinity. The probability of the latter explanation is proved by the decrease of salinity downwards. Such water might also be formed in some places by an intermixture of warmer and more saline water with Polar water (of the Greenland Polar Current); but the water formed in this manner will probably acquire a lower salinity than the other bottom water, because the salinity of the Polar Current is very low, and the warmer water cannot be much cooled merely by contact with the colder water, and without being mixed with it. Fairly cold water with a comparatively high salinity might be formed by the contact of warm water with ice, without being much mixed with the water melting from it; but there are not many places in the Norwegian Sea where this will occur, as a rule. The Polar ice floats southwards in the cold waters (with low salinities) of the Greenland Polar Current, and in the Norwegian Sea, it hardly ever leaves the region of this water. This heavy ice has therefore little opportunity of coming into contact with warmer water with high salinity, and of cooling it down to form bottom-water. The much thinner ice formed each winter over great areas of the northern and western Norwegian Sea itself may, however, do this to a greater extent. It may, for instance, be carried by winds far eastwards into the Norwegian Sea, as sometimes happens in the spring in the region south and east of Jan Mayen; the ice may even be carried towards Bear Island, as was observed by Nansen in March and April, 1882 [cf. 1906, p. 89], and then fairly cold water with comparatively high salinities may be formed by contact with this ice. But it will only last for a short while, as the ice will by melting soon form a surface-layer of light and cold water, which will prevent the contact between the ice and the warm saline water.

Nansen has already pointed out [1906, p. 93] that no bottom-water with low temperatures can anywhere get out of the Norwegian Sea and southwards into the Atlantic. We must assume that the cold bottom-water circulates slowly in the deep basin of this sea, for a very long time, until it shall have been warmed up towards zero C., chiefly by intermixture with the overlying warmer strata, to a much smaller extent from the sea-bottom by the subterranean heat. The bottom-water thus warmed may be carried out with the other currents, chiefly with the Polar Current across the Iceland Greenland Ridge. But the quantity carried out is evidently very small, and the renewal of the Bottom-Water of the Norwegian Sea must be an extremely slow process. On the other hand only very small quantities of bottom-water can be formed each winter by the cooling of the sea-surface in such a limited area as described above. We must consequently conclude that the bottom-water of the Norwegian Sea forming the floor of the currents, remains practically almost unaltered for a very long period of years.

P. S. Since the above chapter had been written a number of water-samples from depths greater than 600 metres, taken during the *Belgica* expedition in 1905, in the Greenland Sea, have been examined by Weighing with the Pyknometer(1) and by Titration at the International Central Laboratory for the Study of the Sea at Christiania. The determinations were made by Mr. BJERKE [cf. HELLAND-HANSEN and KOEFOED, 1909]. As the samples were originally small (300 cub. cm.), and a great part of them had been used for repeated titrations, two and three (and even four in one case) of them were added together to form fourteen greater samples whose quantities were sufficiently great for determinations of specific gravity and for renewed titrations, which were made in the summer of 1908. As the water-samples had then been kept on their bottles during three years, and most of them only filling a small part of the bottles, it is obvious that some evaporation must have taken place, and the values of σ_0 and *Cl* obtained in 1908 must consequently be too high; but the ratio between them may not have altered appreciably, unless the water had dissolved some glass, and σ_0 had become too high comparatively. The strange fact is, however, that the salinities computed from Mr. BJERKE's values of σ_0 are on the whole sligthly *lower* than those obtained by his titrations. If we leave out the determinations of one sample, where the difference (0·07 ‰) was so great that it is probably due to some error, the other 13 samples give a mean difference of about 0·007 ‰ in the salinities computed from σ_0 and from *Cl*. If we leave out the determinations of two more samples where the differences were 0·03, and 0·03 ‰, which seem at any rate to be exceptional, the differences

(1) By a mistake it has been stated by HELLAND-HANSEN and KOEFOED that Mr. BJERKE'S determinations of σ_0 were made by Hydrostatic Weighing.

in the salinities computed from σ_0 and from *Cl* of the other 11 samples, vary between $+0{\cdot}01$ and $-0{\cdot}01$ ‰, and the mean difference is 0·003 ‰. This is so small an amount that it is within the limits of the errors of observation. If it actually represents an existing difference, it would consequently indicate that the amount of *Cl* as compared with σ_0 is slightly greater in the bottom-water of the Greenland Sea than is normal according to KNUDSEN's Tables. If this really be correct it might indicate that the bottom-water has been at the surface of the sea while ice was being formed, which process has a tendency to alter the ratio between *Cl* and especially lime and sulphates (see above). But as we just said, the differences observed are so small that no certain conclusions can be drawn from them.

Through the Organisation for the International Study of the Sea a number of water-samples were collected from different parts of the sea, in the summer of 1906, and were sent to the International Central Laboratory in Christiania, from which they were distributed to five different laboratories in order to be simultaneously examined. One of these samples was taken from 1000 metres at Stat. 308 of the *Michael Sars*, on July 13, 1906, in the Norwegian Sea off the west coast of Norway. It was typical bottom-water with a temperature of $-0{\cdot}90$ ° C.

The determinations at the Central Laboratory gave: σ_0 (by pyknometer) = 28·069, 28·074.

Mean σ_0 = 28·071

σ_0 computed from *Cl* (by titration) = 28·068

Salinity computed from σ_0 (by pyknometer) = 34·931

— — — *Cl* (by titration) = 34·928

Just as this last chapter is going to press we receive a paper by ERNST RUPPIN, on his determinations made at the Oceanographic Laboratory at Kiel of the above-mentioned set of water-samples. His values of the above sample of bottom-water from Stat. 308 of the *Michael Sars* are:

σ_0 (by pyknometer) = 28·071, 28·073, 28·075, 28·071

mean σ_0 = 28·0725

σ_0 computed from *Cl* = 28·065

Salinity computed from σ_0 (by pyknometer) = 34·933

— — — *Cl* (by titration) = 34·924

The agreement between RUPPIN's determinations and those of the Central Laboratory may be considered very good. They both give somewhat higher values of σ_0 and S $^0/_{00}$ by weighing with the pyknometer than by determinations of *Cl*.

The difference in σ_0 is 0·003 (C. L.) and 0·009 (RUPPIN)
mean = 0·006.
The difference in S $^0/_{00}$ is 0·003 $^0/_{00}$ (C. L.) and 0·009 $^0/_{00}$ (RUPPIN)
mean 0·006 $^0/_{00}$.

This difference agrees remarkably well with those found for the samples from the deepest and coldest water-strata of May & June, 1904 (see above p. 337) the mean of which was 0·008 $^0/_{00}$. The agreement is almost too good to be trusted, and it ought to be considered, that we are here very near the limit of the possible errors of observation.

The object of the samples of 1906 was to have the ratio between σ_0, *Cl*, and So_3-investigated, and it was not to determine the absolute values of the water-samples *in situ*. They were, therefore, filtered and it is possible that their σ_0 may have been slightly increased by evaporation during the operation. The above values of σ_0 of the sample from Stat. 308, are not, therefore, directly comparable with the values of σ_0 found in the bottom-water of 1904 and 1900.

Explanation of Tables.

The hours are given from 0 to 24 (from midnight to midnight). All Depths are given in Metres.

Table I

gives the Date, Hour, Number, Position and Sounding of the Observation-Stations taken between August, 1902, and June, 1904. The observations at the Stations of Table I have been published in *Bulletin des résultats acquis pendant les courses périodiques.* Copenhagen, 1902—1904.

Table II

gives the Observations at the Stations taken between July 1900 and May 1902.

The Water-Bottles employed and the names of the observers are given in the heading of each cruise in the following manner:

Water-Bottles: N, The great Nansen Insulated Water-Bottle (cf. p. 51), *PN*, The great Pettersson-Nansen Insulated Water-Bottle (cf. p. 54), *p*, The Small Pettersson Insulated Water-Bottle (cf. p. 55), *N*, The Nansen Stop-Cock Water-Bottle (cf. p. 55).

Obs.: *H.* (= Dr. Hjort), *H.-H.* (= Helland-Hansen), *N.* (= Nansen).

The *Columns* give: *Hour*, the hour of the observations reckoned from 0 to 24, from midnight to midnight. *M*, the depth in metres. $t°$ C., the corrected temperature (Centigrade) *in situ*. * indicates that the temperature was taken with the great Negretti & Zambra Reversing Thermometers (*NZ 18* & *NZ 47*, cf. pp. 34—35). S ‰, salinity found by titration. S' ‰, salinity computed from σ_0 (determined by Hydrometers of Total Immersion). σ_t, density *in situ* (*i. e.* $\left(S\frac{t}{0} - 1\right)$ 1000, according to Knudsen's Tables).

Table III

gives the *Surface-Observations* which have not been introduced in the Plates, especially those taken by Norwegian Sealers and Whalers in the Arctic Seas. The following data are recorded: Date and Hour, Position, Corrected Temperature (Centigrade), and Salinity (*per mille*, according to Knudsen's Tables).

Table I.

Date.	Hour.	Stat.	Position.		Depth Metres	Date.	Hour.	Stat.	Position.		Depth Metres
			Lat.	Long.					Lat.	Long.	
					1902, August.						
			N	W					N	W	
VIII 9	10—11	N. 71	60° 28′	3° 08′	190	VIII 23	11.10—11.40	N. 90	64° 17′	14° 44′	75
» »	15—16	» 72	23′	3° 57′	305	» 24	6— 7	» 92	35′	11° 17′	430
» 10	13—15	» 74	19′	5° 06′	1130	» »	12—12.20	» 93a	49′	9° 45′	
» 11	3— 6	» 75	08′	6° 30′	1100	» 25	7	» 94a	58′	11° 15′	307
» »	20—22.30	» 76	59° 32′	7° 50′		» »	12.20—13	» 94	58′	11° 32′	
» 13	7— 9	» 77	60° 23′	8° 55′	426	» »	13.45	» 95a	56′	11° 45′	227
» »	18—18.30	» 78	55′	8° 56′	126	» »	16.20—18.30	» 95	56′	11° 48′	210
» 14	17—18.30	» 80	61° 06′	9° 21′	400	» »	22	» 96	58′	11° 12′	550
» 15	14.30—14.45	» 82	09′	7° 54′	331	» 26	12.15—12.40	» 97a	17′	12° 35′	265
» 19	19.50—20.10	» 83	62° 29′	7° 37′	110	» »	15.30—16.20	» 97	18′	12° 35′	340
» 20	7— 7.45	» 84	45′	7° 35′	330	» 27	9—11.30	» 98	29′	10° 12′	380
» »	17.50—18.50	» 85	53′	9° 06′	450	» »	18—19	» 99	14′	9° 46′	480
» 21	4.50— 6.20	» 86	59′	10° 38′	460	» 28	17.20—19.20	» 101	62° 54′	9° 13′	460
» »	17.10—18.40	» 87	63° 11′	11° 59′5	430	» 29	17—20.20	» 102	63° 06′	6° 19′	1783
» 22	8.40—10.45	» 88	09′	13° 27′	880	» 30	5.30— 6.30	» 103	62° 18′	4° 36′	275
» »	18.40—19.25	» 89	38′	13° 48′	454						
					1903, February.						
			N	E		II 16	5.15— 7.30	N. 7A	70° 05′	4° 36′	
II 9	20.10—23.15	N. 1	61° 06′	4° 15′					N	E	
» 10	6.50— 9.25	» 2A	56′	2° 40′		» 17	4— 6	» 8A	70° 06′	0° 12′	
» »	19.30—20.50	» 3A	62° 41′	1° 13′		» »	14—17	» 9A	11′	2° 57′	
» 11	18.50—20.50	» 4A	63° 36′	0° 32′		» 18	0.20— 2.30	» 10A	69° 49′	5° 26′	
			N	W		» »	14—16.15	» 11A	23′	8° 07′	
» 14	7.45— 9.30	» 5A	65° 07′	1° 09′		» 19	0.20—2	» 12A	68° 51′	10° 42′	
» »	16.15—19.30	» 6A	43′	3° 01′							
					1903, May—June.						
			N	E					N	W	
V 22	16—18	N. 1	61° 01′	4° 10′		V 30	19.15—20.30	N. 18	67° 24′	5° 06′	
» »	22—24	» 2	17′	3° 22′		» 31	3— 4.30	» 19	23′	2° 35′	
» 23	6— 8	» 3	41′	2° 01′						E	
» »	13—14.15	» 4	62° 02′	0° 43′	275	» »	14.30—15.40	» 20	20′	0° 45′	
				W		» »	23—1.VI 1	» 21	17′	3° 30′	
» »	21.15—23.30	» 5	27′	0° 57′		VI 1	8.30—11.30	» 22	14′	6° 12′	
» 24	4— 5.20	» 6	45′	2° 02′		» »	16.30—19.10	» 23	12′5	9° 19′	452
» »	14—15	» 7	42′	2° 57′		» »	22.15—23.30	» 24	11′	10° 26′	223
» »	20.15—22	» 8	63° 15′5	3° 23′		» 4	3.15— 5	» 25	65° 59′	9° 52′	295
» 25	3.30— 6	» 9	03′	4° 12′		» »	10.30—11.45	» 26	52′	7° 55′	410
» »	14—16	» 10	64° 05′	5° 09′		» »	18.30—20.30	» 27	44′	5° 49′	340
» 26	0.15— 1.30	» 11	65° 05′	6° 04′		» 5	3.45— 5.15	» 28	25′	3° 56′	
» »	10—11.20	» 12	66° 07′	7° 07′		» »	11.30—12.30	» 29	02′	2° 10′	
» »	22—23.15	» 13	58′	8° 42′		» »	19—20.15	» 30	64° 54′	0° 20′	
» 28	18.30—21.30	» 14	68° 12′	12° 09′		» 6	1.45— 3.10	» 31	18′	1° 52′	
» 29	10.10—13	» 15	67° 28′	10° 04′		» »	8.30—10.30	» 32	38′	3° 16′	
» »	21.30—21.15	» 16	24′5	11° 51′		» »	15—17.05	» 33	63° 01′	4° 24′	
» 30	11—13	» 17	26′	7° 35′		» »	18—19.30	» 34	62° 49′	4° 40′	192
					1903, August—September.						
			N	E					N	W	
VIII 9	12.15	N. 1	61° 00′	4° 10′	360	VIII 11	12.30	N. 43	64° 03′	5° 01′	
» »	18.10	» 2	22′	3° 08′	380	» »	20.40	» 44	64° 03′	7° 03′	
» 10	1	» 3	50′	1° 52′	342	» 12	4.40	» 45	10′	9° 15′	
» »	7.30	» 4	62° 11′	0° 46′	304	XI 1	13	» 46	66° 04′	11° 16′	
				W		» »	23.30	» 13	55′	8° 48′	
» »	13	» 5	38′	0° 42′		» 2	9.30	» 47	67° 14′	6° 20′	
» »	20.10	» 41	63° 03′	2° 09′		» »	16	» 18	23′	5° 06′	
» 11	4	» 42	35′	3° 36′		» 3	10.40	» 48	66° 10′	2° 02′	
					1903, November.						
			N	E					N	E	
XI 11	8.30	N. 34	62° 50′	4° 45′	370	XI 12	15.40	N. 52	64° 19′	0° 53′	
» »	13.15	» 33	63° 0′	4° 24′					N		
» »	19.10	» 33A	18′	3° 43′		» 13	2.30	» 53	64° 37′	0° 20′	
» 12	1.15	» 32	36′	3° 0′		» »	10.30	» 54	23′	2° 08′	
» »	8.30	» 51	57′	1° 58′		» »	21.50	» 55	09′	3° 57′	

Date.	Hour.	Stat.	Position.		Depth Metres	Date.	Hour.	Stat.	Position.		Depth Metres
			Lat.	Long.					Lat.	Long.	
			N	W					N	W	
XI 14	5.50	N. 56	63° 54′	5° 45′		XI 17	18.30	N 62	25′	0° 15′	
» »	12.30	» 57	63° 40′	7° 30′					N	E	
» 16	14.40	» 58	62° 41′	5° 39′	400	» 18	1	» 4 B	62° 09′	0° 54′	650
» »	21	» 59	59′	4° 30′		» »	5.40	» 3 B	01′	1° 33′	350
» 17	5.10	» 60	63° 03′	3° 0′		» »	12	» 2 B	61° 46′	3° 0′	415
» »	12.25	» 61	62° 43′	1° 34′		» »	18.50	» 1 B	15′	56′	380
1904, May—June.											
			N	E					N	E	
V 21	18.30	N 1	61° 00′	4° 10′		VI 2	6.50	N 21 A	67° 21′	4° 07′	1286
» »	22.40	» 2	14′	3° 22′		» »	14.45	» 22	12′	6° 22′	1340
» 22	2.30	» 2 C	26′	2° 40′		» »	21.40	» 23 A	07′	7° 50′	1063
» »	5.15	» 3	37′	1° 59′	335	» 3	3.45	» 23	05′	9° 08′	434
» »	9.30	» 4 C	51′	1° 12′	215	» »	8.15	» 24	12′	10° 08′	227
» »	12.0	» 4	59′	0° 42′	303	» 5	7.35	» 25 A	66° 34′	11° 11′	345
			N	W		» »	15.40	» 25	04′	9° 39′	256
» »	16.55	» 62 A	62° 14′	0° 13′		» »	23.40	» 26	65° 45′	7° 56′	362
» »	20.15	» 5	26′	1° 00′		» 6	7.45	» 27 A	30′	6° 20′	415
» »	23.40	» 61	36′	1° 30′		» »	16.45	» 28 A	16′	4° 26′	1028
» 23	2.0	» 6	43′	1° 47′		» 7	1.45	» 29	00′	2° 30′	2690
» »	22.0	» 41	63° 08′	2° 14′		» »	9.15	» 30	64° 49′	0° 37′	
» 24	12.0	» 8	16′	3° 11′					N	W	
» »	22.30	» 63	32′	4° 18′		» »	16.30	» 35	64° 53′	1° 20′	3023
» 25	6.30	» 43	64° 02′	5° 02′		» »	23.0	» 36	55′	2° 52′	1830(1)
» »	23.30	» 64	65° 09′	8° 04′	1427	» 8	6.0	» 49	65° 01′	4° 32′	1830(1)
» 26	9.30	» 65	66° 07′	8° 51′		» »	12.45	» 50	04′	6° 06′	1836(1)
» »	19.30	» 66	67° 02′	9° 35′	1610	« 9	0.45	» 55	64° 11′	3° 45′	
» 27	13.30	» 16 A	30′	11° 10′	1720	» »	9.10	» 67	63° 58′	1° 56′	1830(1)
» 28	18.0	» 15	27′	10° 10′		» »	16.40	» 68	48′	0° 19′	1830(1)
» 30	19.0	» 16 B	35′	12° 18′	1836				N	E	
» 31	12.0	» 17 A	48′	7° 39′		» »	23.10	» 69	63° 42′	0° 56′	1830(1)
» »	21.0	» 18 A	48′	4° 54′		» 10	3.10	» 70	27′	1° 32′	1394
VI 1	6.30	» 19 A	44′	2° 06′		» »	6.40	» 37	12′	2° 06′	1067
			N	E		» »	11.20	» 38	62° 57′	2° 42′	759
» »	14.30	» 20 A	67° 40′	0° 12′	3300(1)	» »	15.10	» 39	42′	3° 20′	480
» »	22.30	» 20 B	30′	1° 55′		» »	18.15	» 40	26′	3° 34′	188

(1) Sounding without bottom.

Table II.

1900, July—September. Water-Bottle: *N*, *PN*, *p*, *n*. Obs.: H-H, N.

Hour.	*M.*	$t°$ C	S ‰	S' ‰	σ_t
Stat. 2. *VII 18.* Geiranger Fjord off Merok. 146 m.					
12.0	0	12·85	3·46		2·79
	10	5·98*	33·98		26·76
	20	7·02	34·61		27·14
	40	·38	·85		·27
	60	·44	·92		·31
	80	·43	·94		·33
	100	·41*	35.00		·38
13.30	140	·40	·01	35·03	·41
Stat. 3. *VII 18.* Stor Fjord, between Ørskog and Søkelv. 550 m.					
16.50	6	10·08	31·73		24·43
	10	7·04	33·92		26·59
	15	6·79	34·28		·91
	20	6·81	·48		27·06
	30	·93*	·74		·26
	40	7·18	·78		·24
	50	·46*	·89		·29
	60	·55	·96		·32
	70	·44*	·98		·37
	80	·41	·96		·35
	100	·41*	35·01		·40
	150	·32	·02		·41
	200	7·25	·06		·45
	250	·06	·07		·47
	300	·06	·08		·49
	350	·04	·09		·50
	400	·05	·10		·51
	550	·07	·11		·52

Hour.	M.	t° C.	S ‰.	S' ‰.	σt.
Stat. 4. *VII 19.* Sule Fjord near Sulø. 420 m.					
	0	10·49	33·27		25·54
	5	·32	·36		·64
	10	8·22	34·02		26·49
	15	6·89	·42		·99
	20	6·79	.46		27 04
	25	·79	·48		·06
	30	·59	·56		.15
	40	·53	·61		·21
	50	·58*	·66		·22
	70	·98	·85		·32
	80	7·02	·87		·33
	100	·15	·96		·38
	150	·16	35·00		·42
	200	·04	·02		·46
	250	·02	·07		·49
	300	·02	·09		·51
	350	·04	·09		·51
Stat. 5. *VII 21.* 62° 29′ N, 5° 29′ E. 220 m.					
16.45	0	11·10	33·57		25·66
15.00	10	10·62	·58		·77
16.05	20	·10	·61		·88
.20	30	7·00	34·34		26·92
15.45	35	6·43			
16.15	40	7·24	·55		27·06
.30	»	6·49	·13		26·82
.35	50	·53	·60		27·19
15.10	60	·50	·69		·26
.15	80	·71	·80		·33
.25	100	·80	·82		·34
.30	150	·80			
.40	200	·89	35·04		·49
Stat. 6 a. *VII 23.* 63° 2′ N, 2° 50′ E. 797 m.					
	0	12·03	34·32		26·08
	50	8·62	35 27		27·41
Stat. 6 b. *VII 23.* 63° 4′ N, 2° 48′ E. 836 m.					
	0	11·67	34·74		26·47
	10	·51	·96		·67
Stat. 7. *VII 23.* 63° 6′ N, 2° 46′ E. 914 m.					
12.30	0	11·67	34·82		26·46
10.25	10	·50	·84		·58
	20	·04	·87		·68
10.30	30	10·18	35·22		27.12
	»	·38			
18.0	»	·02		35·17	·10
	»	9·63			
	»	11·25			
10.30	40	9·15	·17		·25
18.0	»	8·99		·20	·30
	50	·17			
	52	·23	·17		·40
	60	·65	·30		·42
	»	·62		·28	·41
	70	·41	·46		·59
11.45	80	·21	·28	·28	·48
	100	·16	·29	·28	·49
13.15	120	7.74	·28	·26	·53
	140	·32	·28	·26	·59
	160	·19	·42		·75
	180	·10	·37		·72
	200	6·95	·26	·23	·62
	250	.51	·24	·20	·67
	300	·33	·24	·20	·69
3.15p.m.	350	5·99	35·20		20·74
16.55	»	·90*		35·19	·74
	400	·15	·16		·81
16.45	450	3·93	·05		·85
»	»	·74*		·03	·84
	500	2·35*		34·99	·96
	600	— 0·51*	·95		28·10
	700	— 0·92		·93	·11
	800	— 1·01*	·94	·93	·12
	860	— 1·04	·94	·93	·12
17.30	910	— 1·05*		·94	·13
Stat. 8. *VII 24.* 63° 51′ N, 1° 14′ W. 2560 m.					
10.00	0	11·12	35·25		
	20	10·43		35·25	26·98
	30	·31	·30		27·08
	»	9·48	·29		·15
	»	·19	·30		·28
	»	·48	·36		·34
	40	8·58		·26	·34
	50	7·77	·26		·41
	60	·86		·25	·54
	80	·54	·23	·23	·50
	100	·28		·21	·54
	»	·41	·32		·62
	150	6 96	·27	·20	·57
	»	7·03			·60
	200	6·59	·23	·20	·66
	300	4·98	·18	·08	·76
	400	2·62	34·97	·92	·88
	»	·60			
	440	1·99	·94	·93	·94
	500	0·71*		·94	·04
	600	·17*	·96	·93	·05
	800	— 0·35*		·93	·09
	1450	— 0·84*	·94	·93	·11
Stat. 9. *VII 25—26.* 63° 53′ N, 6° 22′ W.					
22.00	0	9·2	35·14		27·21
23.00	»	9·1	·11		·21
»	20	7·27	·03		·40
23.30	40	5·90	·03	34·99	·61
3.00	50	4·19			
23.45	60	5 02	·05		·73
3.15	»	3·66	·08?		·90
24.00	80	·65	34·99		·84
0.20	100	·34		35·08	·94
.40	150	1·79	·92		·94
1.00	200	0·73	·89	34·85	·96
3.40	270	·71	·95		·98
1.30	300	1·03	·97	·92	28·00
2.00	400	0·31	·95	·92	·04
	500	·06*		·94	·07
	600	— 0·16*	·92	·89	·05
	800	— ·54*	35·14?	·93	·09
	1000	— ·74*			
	1200	— ·86*	34·95?	·91	·10
	1400	— ·94*	·95?	·91	·10
Stat. 9 a. *VII 27.* 63° 53′ N, 7° 24′ W. 2134 m.					
	1800	— 1·02*	34·94	34·91	28·10
15.00	2030	— ·04	·93		·12
	2100	— ·05*	·93	34·91	·10
Stat. 10. *VII 28.* 64° 53′ N, 10° 0′ W. 622 m.					
3.0	0	9·4			
»	10	8·88	35·03		27·18

Hour.	*M.*	*t*° C.	*S* ‰	*S′* ‰	σ*t*
3.15	20	8·30	·27	35·25	·42
.40	40	·23	·28		·51
4.15	60	7·79	·31	·26	·52
.35	80	·64	·29	·25	·54
5.0	100	·61	·30		·59
.15	160	·18	·25	·20	·58
	200	3·90*	·04	34·97	·77
9.35	250	·07			
	300	0·11*	34·91	·85	·99
	400	— 0·33*	·94	·91	28·07
	500	— ·60*	·94	·91	·08
	600	— ·68*	35·02	·91	·09
Stat. 11. *VII 30.* 66° 34′ N, 20° 33′ W. 210 m.					
11.0	0	8·45	34·68		26·98
	20	7·29	·87	34·79	27·24
11.20	40	6·90	·87	·81	·31
11.35	60	·12	35·02	·97	·54
11.50	80	5·90	·06	35·01	·60
	100	·99*		·05	·62
	150	·38*		·06	·69
	210	·36*		·08	·72
Stat. 12. *VII 30.* 66° 30′ N, 22° 20′ W. 65 m.					
17.25	0	9·0	34·54		26·78
.50	10	8·29	·62		·96
.30	20	·27	·65		·98
.35	30	·17	·67	34·65	·99
18.05	40	·22			
.20	»	·33	·62		·96
17.15	50	7·87	·72		27·10
18.30	»	8·28	·64	·61	26·95
17.25	65	7·80	·71		27·11
Stat. 13. *VIII 3.* 66° 42′ N, 26° 40′ W. 550 m. & 576 m.					
16.55	0	2·75			
14.55	20	3·23	33·78	33·77	26·90
15.05	40	2·28	34·11	34·14	27·29
18.05	50	1·19	·13		·35
15.20	60	— 1·02	·23	·23	·55
.35	80	— ·42	·41		·70
18.10	»	— ·26*		·31	·63
16.15	100	— ·63	·44	·42	·71
17.35	120	— 0·45	·57		·80
16.40	150	— ·85	·59	·57	·82
17.00	200	— ·83	·67	·67	·90
17.30	300	0·94	·93		18·01
»	»	·94*		·90	·00
16.45	400	·88*	·96	·94	·03
.15	500	·14*	·96	·94	·07
15.30	550	·14*	·95	·94	·07
Stat. 14 a. *VIII 3.* 347 m.					
23.30	0	9·4			
»	20	·19	35·05		27·13
.35	40	8·82	·03		·19
Stat. 14 b. *VIII 4.*					
0.15	0	5·35	32·90		25·99
.10	40	8·88	35·04		27·19
.20	100	6·37	·13		·63
Stat. 14 c. *VIII 4.*					
1.10	0	5·9			
·20	»	4·55	32·70		25·93
·10	25	7·87	34·88		27·22

Hour.	*M.*	*t*° C.	*S* ‰	*S′* ‰	σ*t*
Stat. 14. *VIII 4.* 66° 28′ N, 25° 18′ W.					
1.40	0	9·4	34·93		27·01
.55	20	26	35·02		·11
.45	40	12	·05	35·01	·13
2.00	60	6·96	34·87		·34
.05	80	55	35·12		·59
.10	100	41	·14	·10	·62
.20	150	05	·14		·68
.30	200	5·99	·14	·10	·66
.40	250	3·63	34·88	34·87	·74
.50	300	0·92	·81	·74	·87
3.05	350	— 0·06	·83	·81	·98
Stat. 15. *VIII 5.* 66° 45′ N, 15° 36′ W. 200 m.					
10.40	0	6·8	33·88		26·59
.55	20	·26	·96	33·91	·68
12.5	25	4·75	34·15	34·14	27·04
11.55	30	3·20	·34	·33	·35
.05	50	2·20	·60	·57	·63
.20	100	·30	·66	·67	·70
.30	150	·47	·78	·74	·75
.45	200	·39	·79	·77	·78
13.10	20	6·20			
.15	»	4·81	34·14		·04
.18	»	·64			
.21	»	5·26			
.25	»	·21			
.30	»	·22			
.33	»	·03			
.35	»	·02			
.40	»	6·02			
.45	»	5·87			
.50	»	6·52			26·68
Stat. 16. *VIII 5.* 67° 7′ N, 15° 3′ W.					
19.0	0	7·5	33·93		26·52
.10	20	·23	·96		·59
.15	50	2·34	34·60		27·64
Stat. 17. *VIII 6.* 67° 28′ N, 14° 30′ W.					
22.0	0	7·5	34·04		26·61
23.25	10	7·12	33·98		·63
22.0	20	5·66	34·07	34·04	·86
23.20	30	2·12	·36		27·47
22.10	55	0·47	·60	·54	·73
23.30	70	·59	·65		·81
22.15	100	·71	·79		·92
.25	200	— 0·89	·79	·77	·98
.35	300	— ·28	·91	·88	28·05
.45	400	— ·13	·96	·90	·06
Stat. 18. *VIII 6.* 69° 9′ N, 12° 0′ W. 1618 m.					
17.10	0	5·7	34·24		27·02
18.10	10	·70	·20		26·98
17.05	20	·51	34·29	34·29	27·07
18.05	25	1·94	·39		·52
17.45	30	— 0·90	·43		·71
.55	40	— 1·32	·54		·81
16.55	50	— ·42	·57	·57	·84
17.15	100	— ·01	·72	·74	·97
.25	200	0·63	·95	·94	28·04
.35	300	·24	·96	·94	·07
	600	·41	·96	·93	·04
	1000	— 0·72	·97	·93	·10
	1300	— ·86	·96	·92	·10
	1500	— ·95	·95	·92	·10

Hour.	M.	$t°$ C.	S ‰.	S' ‰.	σ_t.
Stat. 19. *VIII 7.* 70° 35′ N, 11° 10′ W. 1398 m.					
8	0	4·5			
7.50	20	·26	34·31	34·27	27·20
8.05	50	—1·36	·57	·53	·81
.15	100	—0·45	·82	·74	·94
.20	200	0·25	·93	·89	28·03
.45	300	·22	·95	·93	·06
9.10	400	—0·06	·97	·93	·07
	600	— ·45*	·96	·93	·08
	1300	— ·88*			
Stat. 19 a. *VIII 7.* 5 miles from Stat. 19 towards Jan Mayen.					
10.20	0	4·52	34·29		27·19
»	10	·33	·33		·23
.30	15	·31	·33		·24
.10	20	1·40	·52		.65
Stat. 20. *VIII 7.* 70° 47′ N, 10° 40′ W. 1207 m.					
12.30	0	4·6	34·34		27·23
.25	20	·23	·47		·36
.30	40	1·78	·74		·81
.40	60	0·72	·79		·92
.35	100	·54	·88	34·86	·98
.45	150	·40	·88		28·01
.55	200	·25	·94	·89	·02
13.05	300	·08	·97	·92	·06
Stat. 21. *VIII 7.* 70° 45′ N, 9° 52′ W. 1097 m.					
14.35	0	4·1	34·13		27·10
.40	50	—1·53	·56		·83
.35	100	—0·92	·73		·95
.45	200	0·40	·94		28·06
Stat. 22. *VIII 7.* 70° 45′ N, 9° 35′ W. 1089 m.					
15.30	0	3·6	34·14		27·17
.25	50	—0·81	·60		·84
.35	100	— ·09	·82		28·00
Stat. 23. *VIII 7.* 70° 48′ N, 9° 30′ W. 914 m.					
17.00	0	3·8	34·13		27·13
16.55	20	·40	·16		·20
.50	50	—1·27	·52		·79
17.0	100	—0·11	·82		28·00
Stat. 24. *VIII 7.* 70° 51′ N, 9° 24′ W. 680 m.					
18.0	0	3·4	33·82		26·94
»	20	2·67	·97		27·12
.05	35	1·51	34·50		·63
17.45	50	—0·12	·66		·86
.50	100	— ·08	·82		28·00
Stat. 25. *VIII 8.* On the south east side of Jan Mayen.					
11.00	0	4·2	33·30		26·43
10.50	20	2·21	·80		27·02
.55	50	—0·89	34·65		·88
11.05	70	— ·80	·72		·94
.00	100	— ·41	·82		28·01
Stat. 29. *VIII 9.* 70° 46′ N, 6° 32′ W. 1572 m.					
18.00	0	5·0	33·95		26·87
20.30	»	4·7	·69		·69
18.05	20	3·49	34·15		27·19
22.00	»	·55	·17		·19
18.15	40	1·73	·62	34·63	·72
20.20	»	·00	·63		·77
18.30	60	—0·45	34·63		27·85
21.0	70	— ·09	·72		·90
18.35	80	— ·64	·69	34·67	·89
19.00	100	— ·66	·75		·96
22.20	»	0·04		·77	·94
20.30	»	0·66	·85		·96
22.10	»	1·73			
23.00	»	·24			
18.50	150	—0·12	·82		·99
21.00	»	1·09	·94		28·01
.15	200	—0·02	·83	·83	27·99
.30	300	0·35	·96		28·07
.40	400	·22	·97	·93	·06
	600	—0·31	·97	·94	·09
	800	— ·51	·97	·94	·10
21.30	1000	— ·69	·95	·94	·11
22.30	»	— ·68			
22.10	1300	— ·84	·94	·95	·12
	1530	— ·97	·95	·94	·12
Stat. 30. *VIII 10.* 70° 40′ N, 5° 8′ W.					
4.00	0	6·8	34·90		27·39
.15	20	·08	·99		·56
.05	50	2·93	35·01		·93
.20	100	·63	·01		·95
.30	200	·19	·01		·99
Stat. 31. *VIII 10.* 70° 34′ N, 4° 32′ W.					
6.00	0	7·6	35·00		27·36
.10	20	5·60	34·85		·50
.15	50	2·49	·99		·95
Stat. 32. *VIII 10.* 70° 27′ N, 3° 56′ W.					
8.00	0	7·4	35·00		27·39
.10	50	2·39	34·97		·95
Stat. 32 a. *VIII 10.* 70° 23′ N, 3° 40′ W.					
9.15	0	8·3	35·16		27·37
»	50	3·58	·03		·87
Stat. 33 a. *VIII 10.* 70° 20′ N, 3° 20′ W.					
10·30	0	8·4	35·16		27·35
»	20	7·60	·07		·40
Stat. 33 b. *VIII 10.* 70° 17′ N, 3° 4′ W.					
11.30	0	7·8	35·04		27·36
.35	50	3·36			
Stat. 33 c. *VIII 10.* 70° 15′ N, 2° 54′ W.					
11.45	0	7.9	35·06		27·35
.50	40		·05		
Stat. 34 a. *VIII 10.* 70° 15′ N, 2° 30′ W.					
13.00	0	8·5	35·16		27·33
13.5	20	7·96	·17		·44
	50	3·33	34·99		·87
Stat. 34. *VIII 10.* 70° 15′ N, 2° 30′ W. 2761 m.					
14.00	0	8·5	35·16		27·33
.20	20	7·77	·16	35·08	·39
.45	35	·31	·12		·49
.50	45	4·80	·11	·08	·78
.15	50	·35	·09	·06	·84
.30	100	2·97	·05	·00	·91
.40	150	·61	·02	·00	·95
15.00	200	·50	·02	·00	·96
.15	300	·25	·02	.01	·99

Hour.	*M.*	*t*° C.	*S* ‰	*S′* ‰	σ*t*
15.30	400	1·55	34·99	34·97	28·01
.40	500	0·69	·99	·94	·04
22.00	600	·41*	·97	·96	·07
16.00	800	— 0·32	·95	·92	·08
.30	2000	— 1·10*	·94	·91	·10
20.00	2300	— ·1	·93	·91	·10
18.00	2800	— ·1	·94	·91	·10
Stat. 35. *VIII 10—11.* 70° 13′ N, 2° 10′ W.					
24.00	0	8·7	35·15		27·30
»	50	5·23	·16		·79
0.05	100	4.84	·13		·82
Stat. 36. *VIII 11.* 70° 8′ N, 1° 10′ W.					
2.00	0	8·4	35·16		27·35
.07	50	4·98	·11		·79
2.10	100	·22	·13		·89
Stat. 37. *VIII 11.*					
4.00	0	8·3	35·17		27·39
»	60	4·90	·12		·80
.10	100	·33	09		·84
Stat. 38. *VIII 11.* 69° 58′ N, 0° 46 E.					
6.00	0	8·8	35·16		27·29
»	50	6·57	·18		·65
.10	100	5·26	·11		·74
Stat. 39. *VIII 11.* 69° 53′ N, 1° 04′ E.					
8.00	0	8·1	35·15		27·40
.05	50	5·14	·11		·77
.15	100	4·52	·12		·84
Stat. 40. *VIII 11.* 69° 51′ N, 2° 05′ E.					
10.00	0	9·1	35·16		27·24
.10	50	6·08	·17		·70
.15	100	5·25	·14		·78
.25	200	4·31	·13		·88
Stat. 41. *VIII 11.* 69° 51′ N, 4° 15′ E.					
16.00	0	8 4	35·11		27·32
»	20	7·68	·16		·46
.15	100	4·11	·13		·90
.25	400	3·68	·11		·93
Stat. 42. *VIII 11.* 69° 51′ N, 4° 45′ E.					
18.00	0	9 0	35·15		27·26
.20	50	5·83	·14		·71
.05	100	·1	·15		·80
.15	400	3·76	·09		·91
Stat. 43. *VIII 11—12.* 68° 52′ N, 5° 15′ E. 3000 m.					
23.05	0	9 65	35 02		27·05
.00	20	8·91	·12	35·13	·25
.15	45	7·49	·16	·16	·49
.25	100	5·22	·17	·16	·80
.35	150	4·54	·16	·13	·85
0.25	200	·33	·16	·13	·88
.35	300	3·94	·12	·10	·90
1.00	400	·63	·10	·09	·92
.15	500	·36	·09	·09	·95
	600	·08*	·08	·08	·96
	1000	0·14	34·94	34·94	28·07
	1100?	— 0·04		·94	·08
	2000	— 0·94*		·93	·11
	3000	— 1·0	·93	·93	·12

Hour.	*M.*	*t*° C.	*S* ‰	*S′* ‰	σ*t*
Stat. 44. *VIII 12.* 69° 46′ N, 8° 00′ E.					
14.00	0	9·7	35·07		27·07
.15	50	6·59	·14		·61
Stat. 45. *VIII 12.*					
18.25	0	9·7	35·01		27·03
»	50	6·61	·24		·68
.35	100	5·88	·18		·74
.40	400	3 89	·11		·91
Stat. 46. *VIII 13.* 69° 13′ N, 10° 40′ E. 3000 m.					
15.00	0	10·4	34·58		26·58
»	50	8·01	35·13	35·13	27·39
17.00	»	7·25	·14		·52
15.15	75	6·02	·17		·72
.20	100	5·64	·17	·16	·74
19.00	»	·68			
.10	»	.59			
15.30	150	4·96	·15		·82
16.05	200	·58	·15	·13	·85
.20	300	·11	·12	·12	·89
.50	400	3·73	·11	·10	·92
.35	500	·35	·09	·09	·95
	600?	.74	·09	·14	·94?
	700?	·35	·09	·09	·95?
	800	1·60	34·99	·00	28·03
	900	·36	·97	34·98	·03
14.00	1000	— 0·08	·94	·94	·08
	1500?	— ·63		·93	·10
	2000	— ·94	·93	·93	·12
	3000	— 1·02	·93		·12
Stat. 47. *VIII 14.* 68° 55′ N, 13° 16′ E. 1317 m.					
10.45	0	10·1	34·85		26·83
12.15	20	8·69	35·07		27·24
.10	30	7·82	·09		·39
. 4	40	·11	·16		·55
10.50	50	6·92	·17	35.17	26·59
11.00	75	·11	·13		27·66
.10	100	·04	·18	·16	·69
.25	150	5·36	·16		·78
.30	200	4·79	·13	·13	·82
.45	300	·22	·10		·87
12.00	500	3·49	·07	·09	·93
	600	2·47	·05	·04	·99
	800	— 0·17	34·93	34·93	28·08
	1000	— ·73	·94	·94	·10
Stat. 48. *VIII 18.* Off. Ankenes, Ofoten.					
	0	10·0			
	10	9·55	31·10		23·94
	20	8·57	32 20		25·02
	30	7·32	·91		·75
	40	6·53	33·15		26·05
	50	4·74	·39		·45
	100	·08	34·29		27·32
	»	·18	·30		·32
	120	5·06	·51		·30
	150	·57	·68		·38
	250	6·36	·98		·52
Stat. 49. *VIII 18.* Off. Havnes, Ofoten.					
	20	10·0	33·12		25·51
	30	9·71	·13		·56
	50	5·66	·60		26·51

Hour.	M.	t° C.	S ‰	S' ‰	σt
	70	3·51	34·00		27·06
	100	4·41	·34		·24
	150	5·74	·70		.38
	200	6·26	·91		.47
Stat. 50. *VIII 18.* Between Barøen & Lødingen.					
	0	10·90			
	20	·19	33·21		25·54
	50	6·82	·74		26·47
	70	4·78	34·14		27 04
	100	·65	·25		·14
	150	·75	·19		·09
	200	5·85	·25		·00
Stat. 51. *VIII 22.* 10 miles NW of Loppen.					
19.45	0	8·45	34·41		26·76
.25	10	·08	·45		·85
.50	20	7·76	·49		·92
.30	50	·64	·50		·94
.35	100	6·14	·52		27·18
.40	150	4·85	·62		·41
Stat. 52. *VIII 24.* Østerbotten, Porsanger Fjord. 100 m.					
12.15	0	6·98	32·02		25·10
13.40	10	5·83	·81		·87
12.10	20	4·19	33·44		26·55
.30	30	2·56	·73		·93
13.30	40	0·15	34·06		27·36
12.25	50	— 0·66	·18		·50
13.25	70	— ·98	·22		·53
12.20	90	— 1·13	·23		·56
Stat. 53. *VIII 25.* Porsanger Fjord (In the middle of the fjord, a little outside Kistrand). *200 m.*					
10.30	0	7·6	32·65		25·51
to	10	·25	·91		·76
noon	20	6·48	33·70		26·49
	30	5·95	34·04		·82
	40	·63	·16		·96
	50	·43	·19		27·01
	70	4·98	·39		·22
	100	·77	·42		·25
	150	·25	·47		·36
	185	3·62	·52		·47
Stat. 55. *VIII 28.* Porsanger Fjord, 4 miles NE of Lille Tamsø.					
9—11	0	6·6	33·48		26·30
	20	·28	34·15		·88
	40	·33	·19		·90
	60	·29	·25		·94
	80	·45	·35		27·01
	100	5·88	·37		·09
	150	4·85	·47		·29
	200	3·74	·82		·70
	60	6·28			
	80	·46			
Stat. 56. *VIII 28.* 71° 05′ N, 26° 17′ E.					
16—17	0	6·6	34·31		26·95
	20	·83	·59		27·15
	50	·82	·68		·22
	70	·77	·70		·24
	100	·07	·76		·37
	150	5·20	·81		·53
	200	4·49	·89		·67
	300	3·93	·96		·78

Hour.	M.	t° C.	S ‰	S' ‰	σt
Stat. 57. *VIII 29.* 71° 36′ N, 25° 15′ E.					
	0	6·6	34·88		27·40
	20	·47	·92		·45
	50	5·98	·87		·47
	70	·16	·97		·66
	100	4·98	35·00		·70
	150	·27	·02		·80
	200	3·73	·02		·86
	300	·09	·03		·92
Stat. 58. *VIII 30.* 72° 40′ N, 23° 10′ E.					
9—10	0	6·9			
	20	6·63	34·97		27·47
	50	·15	·98		·55
	70	5·05	35·08		·75
	100	4·68	·11		·83
	150	·32	·10		·86
	200	3·90	·11		·91
	300	·21	·09		·96
Stat. 59. *IX 4.* 73° 4′ N, 20° 50′ E.					
11	0	5·3			
to	25	·25	34·72		27·45
noon	50	4·06	35·02		·82
	75	3·83	·07		·88
	100	·73	·09		·91
	150	·44	·07		·92
	200	2·92	·05		·95
	300	·26	·04		28·01
	400	1·82	·08		·07
Stat. 60. *IX 4.* 73° 47′ N, 19° 51′ E.					
17.30	0	3·5	33·88		26·98
	25	4·16	34·59		27·47
	50	1·62	·86		·91
	100	·32	·90		·98
Stat. 61. *IX 4.* 74° 6′ N, 18° 50′ E.					
20.30—	0	1·3	33·15		26·57
21.30	10	·62	·24		·62
	20	— 0·35	34·00		27·34
	30	— 1·13	·22		·54
	40	— ·08	·48		·76
	50	— ·05	·61		·87
	60	— 0·42	·68		·89
	70	0·03	·74		·92
	90	— 0·19	·72		·91
Stat. 62. *IX 5.* 74° 15′ N, 16° 50′ E.					
9.15—	0	4·35	34·64		27·49
10.15	10	5·17	·84		·55
	20	·40	·93		·59
	30	·31	35·04		·69
	40	4·92	·06		·75
	60	·64	·12		·83
	80	·33	·15		·89
	100	·04	·12		·90
	150	3·54	·07		·91
	200	·17	·04		·92
	250	2·09	34·99		·98
Stat. 63. *IX 5.* 74° 15′ N, 15° 0′ E.					
21.40	0	5·55	35·04		27·65
.30	20	·55	34·99		·63
20.50	50	4·83	35·07		·77
21.35	70	·35	·10		·85
20.55	100	3·93	·11		·91

Hour.	*M.*	*t*° C.	*S* ‰.	*S′* ‰.	σ*t*.
21.00	150	3·53	35·08		27·92
.05	200	·04	·06		·95
.15	300	2·58	·02		·97
.25	400	·12	·01		28·00
22.00	600	—0·17	·00	34·99	·13
Stat. 64. *IX 6.* 74° 12′ N, 11° 50′ E.					
9.00	0	4·8			
	20	·79	35·02		27·74
	30	·85	·00		·72
	40	3·35	·06		·92
	50	·63	·06		·89
	60	·25	·09		·96
	75	·11	·12		·99
9.50	100	2·90	·10		28·00
9.45	150	·71	·05		27·97
9.40	200	·51	·05		·98
9 35	300	·31	·05		28·00
9.25	400	1·98	·01		·01
	620	0·80	34·97	34·97	·05
	1040	—0·65	·93	·94	·11
	2145	—1·1	·94	·92	·11
Stat. 65. *IX 6.* 72° 56′ N, 13° 10′ E. 1650 m.					
20.00	0	6·1	35·05		27·59
.40	20	·11			
19.55	50	4·34	35·11		·86
20 35	80	3·93	·11		·91
30	100	·60	·09		·92
.25	150	·15	·09		·96
.20	200	·01	·08		·97
.15	300	2·79	·07		·98
.10	400	·32	·07		28·02
	630	0·49	34·97		·08
22.05	830	—0·45	·93	34·92	·08
21.25	1040	— ·16	·93	·94	·12
	1550	—1·09	·93	·94	·13

Hour.	*M.*	*t*° C.	*S* ‰.	*S′* ‰.	σ*t*.
Stat. 66. *IX 7.* 71° 58′ N, 12° 50′ E. 1975 m.					
	0	6·55	35·00		27·51
9.50	25	·52	·04		·54
.45	50	·15	·05		·59
.40	75	4·67	·17		·88
.35	100	·27	·13		·88
.30	150	3·83	·11		·92
.20	200	·48	·11		·95
.05	300	·06	·11		·99
8.55	400	2·76	·08		·99
Stat. 67. *IX 7.* 71° 10′ N, 12° 12′ E. 2540 m.					
19.30	0	6·9	34·99		27·45
»	25	·25	35·02		·56
.25	50	5·78	·13		·71
.20	75	·04	·15		·81
.15	100	4·73	·16		·85
.10	150	·16			
.5	200	3·72	·12		·93
.00	300	·27			
18.50	400	2·87	·07		·97
Stat. 68. *IX 8.* 69° 37′ N, 11° 28′ E.					
9.00	0	8·1	34·97		27·26
10.00	50	6·60	35·17		·63
9.55	75	·19	·18		·70
.05	100	5·91	·16		·71
.50	150	·53	·16		·75
.30	200	.01	·16		·82
.20	300	4·59	·14		·86
.15	400	3·95	·12		·90
	630	·05	·08	35·08	·97
	845	1·25	34·99	34·97	28·01
	1045	—0·05	·93	·92	·06
	2045	—0·96	·94	·92	·11

1901, January—April. Water-Bottle: *Pn, p.* Obs.: H-H, H.

M.	*t*° C.	*S* ‰.	σ*t*.
Stat. 1. *I 24* (13.0—14.0) Sulenfjord. 403 m.			
0	6·15	32·78	25·81
10	·11	·78	·82
20	·11	·78	·82
30	·36	·82	·81
40	·43	·88	·85
50	·58	·97	·895
60	·61	33·01	·92
80	·98	·29	26·09
100	7·41	·77	·415
130	·40	34·05	·635
150	·40	·34	·87
200	·54	·90	27·285
Stat. 3. *I 28* (20.0—20.40) 62° 40′ N, 5° 10′ E. 115 m.			
0	5·8	33·64	26.525
10	6·12	·71	·545
20	·47	·88	·64
30	·56	·97	·685
40	·57	·99	·70
60	.58	34·03	·73

M.	*t*° C.	*S* ‰.	σ*t*.
80	6·75	34·07	26·74
100	7·21	·52	27·03
115	·24		
Stat. 4. *II 2* (3—5) 63° 02′ N, 3° 40′ E.			
0	7·1	35·00	27·425
10	·08	·00	·425
20	·65	·17	·49
30	·70	·18	·485
40	·63	(·42)	(·68)
50	·66	·18	·495
70	·68	(·34)	(·615)
100	·71	·18	·485
150	·65	·14	·46
200	·38	·15	·505
300	6·90	·14	·575
400	5·62	·14	·735
550	0·31	34·93	.055
Stat. 5. *II 2* (15.0—15.50) 63° 28′ N, 2° 22′ E.			
0	7·0	35·20	27·60
20	6·97	·20	·605

M.	*t*° C.	*S* ‰.	σ*t*.
35	6·97	35·20	27·605
50	·98	·15	·565
100	·52	·16	·62
150	·48	·16	·63
200	·48	·15	·63
300	5·51	·07	·69
400	2·40	34·92	·90
Stat. 6. *II 3* (0.30—1.5) 64° 02′ N, 0° 12′ E.			
0	5·5	35·02	27·65
25	·45	·06	·685
50	·36	(·22)	(·83)
100	·28	·05	·695
150	5·03	·06	·735
250	2·28	34.93	·92
Stat. 7. *II 3* (6.30—7.0) 64° 23′ N, 1° 13′ W.			
0	5·0	35·02	27·70
25	·12	·93	·705
50	·11		
100	·11		

M.	t° C.	S ‰	σt
150	5·11	35·03	27·705
200	3·49	34·96	·83
300	1·56	·96	·99

Stat. 8. *II 3.* (15.45—17.0).
63° 35′ N, 1° 04′ E.

M.	t° C.	S ‰	σt
0	7·0	35·18	27·585
25	·01	·20	·60
50	6·98	·22	·625
75	·99	·22	·62
100	7·01	·20	·60
200	·02	·18	·585
300	6·99	·20	·605
	·99		
400	5·98	35·10	·66

Stat. 9. *II 11* (11.30—12.0).
68° 05′ N, 14° 25′ E. 87 m.

M.	t° C.	S ‰	σt
0	3·8	33·52	26·655
10	4·10	·54	·64
25	·23	·55	·635
50	·28	·55	·63
87	·32	·57	·64

Stat. 10. *II 11* (15.30—16.15).
68° 00′ N, 14° 24′ E. 243 m.

M.	t° C.	S ‰	σt
0	4·4	33·56	26·625
25	·52	·56	·615
50	·53	·57	·615
75	·54	·56	·61
100	·55	·56	·61
150	6·19	34·02	·775
200	5·98		
243	6·03	34·78	27·395

Stat. 10 A. *II 12* (11).
68° 00′ N, 14° 24′ E.

M.	t° C.	S ‰	σt
125	4·39	33·52	26·595

Stat. 11. *II 12* (16.40—17.20).
67° 39′ N, 13° 07′ E.

M.	t° C.	S ‰	σt
0	4·5	33·63	26·675
25	·78	·63	·655
50	·775	·64	·66
75	·775	·61	·64
100	·775	·63	·655
125	·77	·63	·655
150	5·59	·79	·685
175	6·42	34·14	·855
200	6·08	·63	27·28

Stat. 12. *II 13* (17.25—19.5).
67° 54′ N, 14° 00′ E. 290 m.

M.	t° C.	S ‰	σt
0	3·8	33·40	26·56
25	4·07	·57	·665
50	·70	·61	·64
51	·74	·60	·625
65	·49	·54	·60
80	·61	·57	·61
100	·75	·64	·685
125	5·75		
150	6·46	34·48	·31
175	·30	·67	27·27
200	·60	·86	·38
240	·26	·89	·455
275	·22	·89	·46
290	·21		

Stat. 12 A. *II 14* (7.55—8.25).
67° 54′ N, 14° 00′ E.

M.	t° C.	S ‰	σt
20	4·26	33·53	26·615
»	·15	·50	·605
25	·19	·51	·61
40	·22	·53	·62
50	·35	·57	·635
60	·46	·59	·645

Stat. 13. *II 18* (12.25—12.45).
69° 29′ N, 16° 32′ E.

M.	t° C.	S ‰	σt
0	3·9	33·96	26·99
25	·68	·92	·975
50	4·27	34·03	27·00
75	·44	·07	·02
100	·53	·13	·05

Stat. 14. *II 18* (19.0—23.0).
69° 43′ N, 16° 15′ E.

M.	t° C.	S ‰	σt
0	4·6	34·12	27·04
25	·78	·31	·175
50	·99	·51	·31
75	·85	·49	·305
100	5·88	·68	·33
125	·43	·62	·355
150	6·04	·90	·495
200	·03	·98	·56
300	5·75	35·06	·65
400	·47	·09	·715
500	4·97	·06	·745
700	3·94	·05	·845
900	2·52	·00	·96

Stat. 15. *II 22* (17.10—19.0).
69° 50′ N, 15° 05′ E.

M.	t° C.	S ‰	σt
0	4·7	34·97	27·715
25	5·01	35·04	·725
50	·18	·03	·70
75	·25	·08	·73
100	·16	·10	·76
150	·03	·09	·765
200	4·84	·09	·79
300	·00	·11	·895
400	(·71)	(34·96)	(·69
»	3·55	35·09	·925
600	2·45	·03	·985
800	0·14	34·87	(28·01
1000	0·40	35·00	·15

Stat. 16. *II 23* (1.0—2.0).
69° 59′ N, 12° 50′ E.

M.	t° C.	S ‰	σt
0	4·7		
25	·66	35·08	27·80
50	·68	·11	·82
75	·68	·08	·792
100	·66	·08	·80
150	·53	·08	·81
200	·21	·08	·845
300	3·92	·05	·85
400	·37	·07	·925

Stat. 17. *II 23* (9.0—11.0).
70° 10′ N, 10° 10′ E.

M.	t° C.	S ‰	σt
0	5·6	35·08	27·69
25	·63	·09	·695
50	·48	·10	·72
75	5·73	35·10	27·69
100	·73	·10	·69
150	·33		
200	·65	·09	·695
300	·61	·08	·69
400	·49	·12	·73
600	4·06	·07	·855
800	3·19	·08	·95

Stat. 18. *II 28* (15.0—15.45).
71° 04′ N, 23° 40′ E. 200 m.

M.	t° C.	S ‰	σt
0	3·1	34·41	27·425
25	3 08	·40	·425
50	·08	·40	·425
75	·09	·39	·415
100	·09	·42	·43
125	·06	·42	·435
150	·14	·43	·445
190	·86	·59	·49

Stat. 19. *III 3* (8.0—9.0).
71° 20′ N, 23° 40′ E.

M.	t° C.	S ‰	σt
0	3·4	34·76	27·67
25	·42	·76	·67
50	·53	·77	·665
75	·64	·81	·695
100	·87	·86	·705
125	·88	·87	·71
150	·95	·88	·715
200	4·28	·97	·76
300	·17	35·07	·84

Stat. 20. *III 3* (13.20—14.15).
71° 55′ N, 22° 40′ E.

M.	t° C.	S ‰	σt
0	3·5	34·85	27·73
25	·52	·85	·73
50	·53	·89	·765
75	·54	·89	·765
100	·56	·90	·775
125	·69	·90	·76
150	·83	·98	·81
200	·76	·99	·825
300	·90	35·05	·85

Stat. 21. *III 3* (18.10—19.0).
72° 30′ N, 21° 40′ E.

M.	t° C.	S ‰	σt
0	3·8	35·03	27·85
25	·84	·03	·845
50	·80	·05	·86
75	·87	·06	·865
100	·90	·07	·87
125	·93	·07	·865
150	·92	·07	·87
200	·83	·07	·875
300	·29	·07	·93

Stat. 22. *III 3* (23.15)—*4* (0.20).
73° 08′ N, 20° 37′ E.

M.	t° C.	S ‰	σt
0		35·06	27·965
25	2·93	·06	·965
50	·93	·07	·975
75	·93	·07	·975
100	·93	·07	·975
125	·93	·07	·975
150	·95	·07	·975
200	·93	·07	·975
300	·63	·06	·99

Stat. 23. *III 4* (4.30—5.30).
73° 45′ N, 19° 42′ E.

M.	t° C.	S ‰	σ_t
0	3·0	35·05	27·94
25	·0	·05	·94
50	·0	·05	·94
75	2·90	·05	·96
100	2·58	·05	·985
125	·19	·05	28·015
150	·06	·03	·015
200	·02	·02	·01
300	1·62	00	·025

Stat. 24. *III 4* (6.0—6.35).
73° 50′ N, 19° 30′ E.

M.	t° C.	S ‰	σ_t
0	−1·4	34·43	27·72
25	0·66	·78	·915
50	1·37	·95	28·00
50	·56	·94	27·98
75	·67	·99	28.015
100	·67	35·01	·03
125	·80	·01	·02
200	·68	34·99	·015

Stat. 25. *III 4* (14.10—15.5).
73° 20′ N, 19° 00′ E.

M.	t° C.	S ‰	σ_t
0	4·2	34·99	27·78
25	·15	35·02	·805
50	·15	·02	·805
75	·15	·03	·815
100	·15	·03	·815
125	·15	·03	·815
150	·14	·03	·815
200	·14	·07	845
300	3·76	·08	·895
400	2·39	·03	·99

Stat. 26. *III 4* (21.10—22.15).
72° 55′ N, 15° 50′ E.

M.	t° C.	S ‰	σ_t
0	4·3	35·05	27·805
25	·29	·05	·81
50	·27	·06	·82
75	·25	·06	·825
100	·22	·06	·825
125	·10	·07	·85
150	3·93	·06	·855
200	·60	·05	·88
300	2·98	·04	·945
400	1·73	34·99	28.01

Stat. 27. *III 5* (8.40—9.30).
72° 05′ N, 19° 24′ E.

M.	t° C.	S ‰	σ_t
0	4·4	35·03	27·785
35	·41	·03	·785
75	·43	·04	·785
100	·465	·04	·785
125	·52	·05	·795
150	·52	·05	·790
200	·54	·04	·785
300	·40	·10	·855

Stat. 28. *III 5* (22.15—23.5).
71° 00′ N, 21° 35′ E. 250 m.

M.	t° C.	S ‰	σ_t
0	4·3	34·90	27·695
25	·285	·90	·70
50	·49	·96	·715
75	4·335	34·99	27·765
100	·35	·99	·76
125	3·95	·96	·775
150	4·21	·99	·775
200	·23	35·00	·785
240	·10	34·98	·785

Stat. 29. *III 13* (7.0).
70° 21′ N, 31° 18′ E.

M.	t° C.	S ‰	σ_t
0	2·5	34·51	37·465
50	·63	·54	·485
100	·19	·62	·585

Stat. 30. *III 15* (8.0—9.0).
69° 50′ N, 33° 00′ E. 160 m.

M.	t° C.	S ‰	σ_t
0	1 60	34·61	27·715
25	·63	·53	·645
50	·68	·63	·72
75	·67	·58	·685
100	·67	·55	·66
160	·65	·58	·685

Stat. 31. *III 15* (15.0).
70° 14′ N, 32° 30′ E. 180 m.

M.	t° C.	S ‰	σ_t
0	2·24	34·66	27·70
25	·29	·60	·645
50	·30	·60	·645
100	·30	·61	·655
150	·31	(35·42)	(28·30)

Stat. 32. *III 16* (6.30).
70° 24′ N, 31° 20′ E.

M.	t° C.	S ‰	σ_t
0	2·83	(35·01)	(27 935)
25	·87	34·47	·49
50	·89	·53	·54
100	·94	·52	·525
200	·93	·53	·535

Stat. 33. *III 19* (9.0).
70° 40′ N, 31° 40′ E.

M.	t° C.	S ‰	σ_t
10	2·56	34·60	27·62
100	·61	·57	·595
200	·72	·66	·655

Stat. 34. *III 27* (7.0).
3 naut. miles N of Makur.

M.	t° C.	S ‰	σ_t
0	2·8	34·54	27.56
25	·79		
50	·81	·52	·54
100	·63	·52	·555
200	·51	·54	·585

Stat. 35. *III 29* (15.0).
71° 00′ N, 26° 18′ E.

M.	t° C.	S ‰	σ_t
0	2.8	34·52	27·54
25	·80	·47	·50
50	·75	·50	·52
100	·78	·53	·55
150	·79	·60	·60

Stat. 38. *IV 2* (10.0).
70° 34′ N, 21° 27′ E.

M.	t° C.	S ‰	σ_t
0	3·1	34·55	27.535
25	·38	·65	·59
50	·55	·75	·65
100	4·11	·81	·65
200	.16	·92	·72

Stat. 42. *IV 9* (20.0).
69° 53′ N, 17° 22′ E.

M.	t° C.	S ‰	σ_t
0	2·84	34·01	27·13
25	·88	33 95	·08
50		34·05	
80	·97	·04	·14

Stat. 43. *IV 13* (20.0).
68° 57′ N, 12° 48′ E.

M.	t° C.	S ‰	σ_t
0	4·5	34·50	27·355
50	5·40	·98	·635
100	·48	35·07	·69
230		·09	·715
400	4·56	·07	·805

Stat. 44. *IV 15* (20.0).
67° 45′ N, 13° 50′ E.

M.	t° C.	S ‰	σ_t
0	2·8	33·63	26·83
25	·86	·61	·81
50	3·50	·85	·935
100	6.11	34·63	27·265
200	6·58	35·04	·515

Stat. 45. *IV 16* (7.0).
Vestfjorden, off Svolvær.

M.	t° C.	S ‰	σ_t
0	2.5	33·51	26·765
25	·81	·68	·87
50	3·20	·78	·91
100	6·25	34·52	27·16
200	·37	35·03	·55

Stat. 46. *IV 24* (11.0).
70° 48′ N, 23° 43′ E.

M.	t° C.	S ‰	σ_t
0	2·7	34·35	27·42
25	·68	·35	·42
50	·69	·37	·435
100	·71	·37	·435
150	·71		
200	·87	34·47	·49

Stat. 47. *IV 24* (18.30).
71° 10′ N, 24° 02′ E.

M.	t° C.	S ‰	σ_t
0	3·3	34·42	27·41
10	·20	·42	·42
25	·20	·41	·415
50	2·76	·40	·45
100	·91	·47	·49
150	·91	·52	·53
200	3.72	·84	·705

1901, May. Water-Bottle: *PN, p.* Obs. H-H.

Stat. 1. *V 5* (1·30—2·0)
60° 58′ N, 3° 50′ E.

M.	t° C.	S ‰.	σt.
0	6·2	32·57	25·635
50	5·75	34·43	27·15
100	6·81	·93	·405
150	7·07	35·19	·58
200	6·92	·16	·58
250	·80	·16	·595

Stat. 2. *V 5* (7.45—8.15)
61° 20′ N, 2° 42′ E.

M.	t° C.	S ‰.	σt.
0	7·2	33·98	26·61
50	·64	35·22	27·515
100	·51	·28	·585
150	·31	·29	·625
200	·26	·31	·645

Stat. 3. *V 5* (14.0—14.50)
61° 48′ N, 1° 04′ E.

M.	t° C.	S ‰.	σt.
0	9·3	35·32	27·33
25	8·50	·26	·425
50	7·52	·26	·575
75	·43	·27	·59
100	·25	·25	·59
150	·18	·26	·62
200	·13	·26	·635

Stat. 4. *V 5* (20.25—21.15)
62° 10′ N, 0° 10′ W.

M.	t° C.	S ‰.	σt.
0	8·9	35·21	27·325
10	·64	·21	·365
25	7·20	·17	·54
50	6·31	·15	·65
100	5 34	·07	·71
150	4·41	·02	·78
200	3·73	·01	·845
250	2·93	34·94	·865
400	1 16	·90	·98

Stat. 5. *V 6* (2.40—3.30)
62° 28′ N, 1° 11′ W.

M.	t° C.	S ‰.	σt.
0	8·3	35·23	27·425
25	7·04	·23	·615
50	6·73	·23	·655
75	·56	·22	·675
100	·48	·21	·675
150	·14	·20	·71
200	5·55	·14	·745
300	3·63	·03	·87
400	1·23	34·94	28·005

Stat. 6. *V 6* (10.45—11.30)
63° 00′ N, 1° 45′ W.

M.	t° C.	S ‰.	σt.
0	8·2	35·17	27·40
10	7·96	·23	·475
25	·09	·22	·60
50	6·67	·21	·655
75	·37	·21	·695
100	·03	·18	·71
150	5·39	·11	·735
200	3·69	·03	·86
300	1·38	34·85	·95
400	0·44	·89	28·01

Stat. 7. *V 6* (14.30—14.45)
63° 17′ N, 2° 00′ W.

M.	t° C.	S ‰.	σt.
0	8 0	35·24	27·475
25	6·41	·18	·665
50	5·90	·16	·71

Stat. 8. *V 6* (22.35—23.15)
63° 16′5 N, 2° 36′ W.

M.	t° C.	S ‰.	σt.
25	7·04	35·20	27·595
50	6·32	·32	·78
75	5·90	·19	·73
100	[6·55]	[·20]	
150	4·36	·05	·80
200	3·25	34·96	·845
300	1·81	·88	·915

Stat. 9. *V 8* (19.40—20.45)
63° 03′ N, 2° 59′ W.

M.	t° C.	S ‰.	σt.
0	7·4	35·17	27·52
10	·13	·14	·53
25	5·74	·11	·695
50	4·57	·04	·77
75	3·85	·00	·825
100	·26	34.99	·875
150	2·22	·90	·90
200	1·32	·88	·945
250	0·82	·88	·975
300	·40	·88	28·00
400	·11	·88	·03

Stat. 10. *V 9* (10.30—12.0)
64° 08′ N, 4° 52′ W

M.	t° C.	S ‰.	σt.
0	7·0	35·08	27·50
10	6·37	·07	·59
25	4·33	34·98	·76
50	3·51	·96	·82
75	·10	·93	·84
100	·00	·92	·84
125	2·99	·93	·85
150	·95	·93	·855
200	·92	·93	·86
300	·19	·89	·89
400	1·66	·90	·945

Stat. 11. *V 9* (20.20—21.15)
64° 53′ N, 5° 53′ W.

M.	t° C.	S ‰.	σt.
0	5·0	34·91	27·625
»	4·70	·86	·615
10	·61	·91	·67
25	3·29	·87	·77
50	2·38	·92	·895
75	·07	·90	·915
100	1·89	·89	·92
125	·90	·91	·935
150	·94	·94	·955
200	1·62	·92	·955
300	·35	·94	·995
400	0·70	·91	28·015

Stat. 12. *V 10* (10.10—11.00)
66° 03′ N, 8° 56′ W.

M.	t° C.	S ‰.	σt.
0	2·0	34·75	27·795
10	1·61	·73	·805
25	·50	·74	·825
50	—0·15	·75	·935
75	— ·29	·74	·935
100	—0·17	34·77	27·95
125	—0·06	·81	·985
150	— ·02	·82	.985
200	0·07	·85	·995
300	—0·01	·86	28·01
400	— ·09	·91	·06

Stat. 13. *V 10* (20.25—21.0)
66° 51′ N, 9° 47′ W.

M.	t° C.	S ‰.	σt.
0	0·9	34·60	27·745
25	0·75	·71	·85
50	—0·21	·67	·87
75	—0·50	·67	·885
100	— ·55	·70	·92
150	— ·24	·80	·98
200	— ·15	·84	28·005
300	0·06	·91	·05

Stat. 14. *V 14* (21.25) — *15* (2.0)
67° 20′ N, 11° 10′ W.

M.	t° C.	S ‰.	σt.
0	0·2	34·45	27·67
10	—0·03	·44	·675
25	— ·03	·45	·68
50	— ·55	.53	·775
75	—1·67	·63	·895
100	—0·16	·74	·93
»	—1·48	·68	·93
125	—0·84	·75	·965
150	— ·19	·85	28·01
200	0·27	.90	·035
300	·06	·94	·075
400	— ·09	·93	·075
500	— ·22	·91	·065
800	— ·55	·92	·09
1000		(·89)	

Stat. 15. *V 15* (18.45—19.35)
67° 17′ N, 8° 02′ W.

M.	t° C.	S ‰.	σt.
0	1·5	34·73	27·815
10	·48	·76	·835
25	·30	·74	·84
50	0·90	·82	·93
»	·85	·80	·92
75	1·95	·99	·995
100	·95	·98	·99
125	·65	·98	28·01
150	·52	·97	·015
200	·26	97	·03
300	0·84	·94	·03

Stat. 16. *V 16* (4.30—5.15)
67° 22′ N, 5° 20′ W.

M.	t° C.	S ‰.	σt.
0	2·7	34·95	27·89
25	3·29	·98	·865
50	2·25	35·01	·985
75	·23	·01	·99
100	·24	·03	28·00
150	·09	·01	·00
200	·06	·01	·005
300	·07	·01	·005
400	[·16]	[·00]	[27·985]

Stat. 17. *V 16* (13.25—14.15)
67° 26′ N, 2° 06′ W.

M.	t° C.	S ‰.	σt.
0	4·5	35·07	27·805
10	·72	·06	·77

M.	t° C.	S ‰	σt
25	4·72	35·05	27·76
50	·62	·06	·78
75	·24	·07	·835
100	·10	·07	·85
150	3·51	·04	·885
200	·24	·04	·91
300	2·37	·00	·965
400	1·89	34·93	·95

Stat. 18. *V 16* (22.25—24.0).
67° 30′ N, 0° 41′ E.

M.	t° C.	S ‰	σt
0	5·5	35·12	27·71
25	6·03	·12	·665
50	5·92	·10	·67
75	4·54	·05	·78
100	·23	·04	·81
150	3·80	·05	27·86
200	2·77	34·98	·915
300	·13	·93	·925
500	0·68	·92	28·02
600	·16	·92	·05

Stat. 19. *V 17* (8.0—9.0).
67° 34′ N, 3° 37′ E.

M.	t° C.	S ‰	σt
0	6·2	35·16	27·665
25	·32	·15	·65
50	·31	·14	·645
75	5·31	·13	·765
100	·18	·12	·765
150	·01	·11	·785
200	4·82	·13	·82
300	·31	·11	·86
400	2·80	·00	·93

Stat. 20. *V 17* (15.25—16.10).
67° 37′ N, 6° 00′ E.

M.	t° C.	S ‰	σt
0	6·0		
25	5·86	35·23	27·77
50	·85	·23	·77
75	·08	·14	·80
100	4·99	·14	·81
150	·66	·11	·82
200	·52	·13	·855
400	2·96	·02	·93

Stat. 21. *V 17* (23.45)—*18* (1.0).
67° 41′ N, 8° 30′ E.

M.	t° C.	S ‰	σt
0	6·4	35·14	27·635
10	7·04	·15	·55
25	6·98	·17	·58
50	·68	·12	·575
75	·63	·16	·61
100	·15	·15	·675
150	5·57	·13	·73
200	·30	·16	·785
300	4·92	·15	·825
400	·12	·08	·855
500	2·23	·00	·98
600	0·47	34·94	28·05

Stat. 22. *V 18* (7.15—8.0).
67° 35′ N, 10° 50′ E. 162 m.

M.	t° C.	S ‰	σt
0	6·4	34·25	26·93
20	5·54	·34	27·115
40	·61	·35	·11
60	·69	·72	·385
80	6·00	·80	·42
100	·13	·93	·505
130	·11	35 08	·625
160	·12	·11	·65

1902, May. Water-Bottle: *PN, p.* Obs.: H-H.

Stat. 1. *V 6* (16.20—17.5).
60° 48′ N, 4° 16′ E. 380 m.

M.	t° C.	S ‰	σt
0	6·0		
25	5·50	32·5	25·66
50	·28	33·57	26·525
75	·73	34·32	27·065
100	6·08	·65	·28
150	·58	·96	·46
200	·98	35·18	·585
300	·80	·25	·655
380	·50	·20	·655

Stat. 2. *V 6* (22.30—23.20).
61° 11′ N, 3° 11′ E.

M.	t° C.	S ‰	σt
0	6·1		
25	·29	34·53	27·16
50	·29	·89	·45
75	·52	·91	·435
100	·82	35·07	·515
150	7·26	·15	·52
200	·30	·23	·575
320	6·93	·23	·63

Stat. 3. *V 7* (6.0—6.30).
61° 36′ N, 1° 47′ E.

M.	t° C.	S ‰	σt
0	6·9	33·68	26·545
25	8·16	35·29	27·495
50	·04	·29	·515
75	7·88	·29	·535
100	·72	·28	·555
125	·62	·28	·57
170	·28	·28	·615

Stat. 4. *V 7* (10.50—11.45).
62° 00′4 N, 0° 14′ E.

M.	t° C.	S ‰	σt
0	8·3		
25	·63	35·32	27·44
50	·77	·32	·415
75	·48	·35	·49
100	9·22	35·32	27·345
150	·49	·29	·28
200	8·20	·28	·48
300	·01	·28	·51

Stat. 5. *V 7* (16.45—17.30).
62° 19′ N, 0° 49′ W.

M.	t° C.	S ‰	σt
0	7·7		
25	·89	35·27	27·52
50	·61	·27	·57
75	·42	·25	·575
100	6·95	·21	·62
150	·62	·18	·635
200	5·79	·15	·72
300	2·98	34·93	·865

Stat. 6. *V 8* (0.40—1.30).
62° 32′ N, 1° 40′ W.

M.	t° C.	S ‰	σt
0	7·2	35·25	27·60
25	7·33	·20	·555
50	·30	·20	·56
100	·27	·20	·56
150	6·94	·21	·62
200	·60	·19	·64
300	5·19	·08	·74
400	2·34	34·90	·91

Stat. 7. *V 8* (7.0—8.0).
63° 02′ N, 1° 56′5 W.

M.	t° C.	S ‰	σt
0	5·8	35·19	27·755
25	·90	·09	·66
50	4·94	·07	·755
75	3·41	34·93	·81
100	5·46	35·07	·695
»	2 91	34·92	·855
150	1·71	·90	·94
200	·46	·88	·94
300	·14	·94	28·01
400	0·47	·91	·025

Stat. 8. *V 9* (15.0—16.0).
62° 26′ N, 2° 29′ W.

M.	t° C.	S ‰	σt
0	7·6	35·34	27·625
25	·57	·22	·535
50	·43	·22	·555
75	·41	·22	·555
100	·25	·22	·58
150	·04	·19	·585
200	6·51	·19	·655
300	4·57	·03	·77
400	1·57	34·88	·925

Stat. 9. *V 10* (8.0—11.0).
62° 50′ N, 3° 08′ W.

M.	t° C.	S ‰	σt
0	8·1	35·34	27·545
25	·11		
50	7·86	(35·32)	(·57)
75	·64	·25	·54
100	·56	·24	·545
150	6·85	·23	·64
200	·43	·17	·655
300	4·34	·04	·80
400	1·55	34·91	·955
600	0·44	·94	28·055

Stat. 10. *V 10* (16.30—17.15).
63° 16′ N, 3° 35′ W.

M.	t° C.	S ‰	σt
0	7·2	35·26	27·62
25	·34	·23	·57
50	6·95	·19	·595
75	·64	·17	·625
100	·40	·17	·66
150	5·12	·10	·765
200	2·97	34·91	·845
300	1·79	·98	28·00
400	1·34	·96	·005

Stat. 11. *V 11* (10.20—11.10).
64° 48′ 5 N, 7° 06′ W.

M.	t° C.	S ‰	σt
0	2·2	34·94	27·935
25	·23	·84	·85
50	.10	·84	·86
75	1·65	·86	·90
100	·34	·86	·92
150	·69	·90	·94
200	2 01	·99	·99
300	1.57	·94	·98
400	·09	·95	28·02

Stat. 12. *V 11* (16.0—17.0).
65° 21′ N, 7° 52′ W.

M.	t° C.	S ‰	σt
0	0·35	34·67	27·84
25	·21	·59	·78
50	·13	·60	·795
75	— ·32	·67	·875
100	— ·36	·68	·885
150	— ·19	·76	·94
200	·55	·87	·99
300	·46	·93	28·04
400	·23	·94	.065

Stat. 13. *V 11* (22.0—23.5).
65° 58′ N, 8° 42′ W.

M.	t° C.	S ‰	σt
0	—0·3	34·51	27·745
25	— ·04	·47	·70
50	— ·52	·52	·765
75	— ·76	·56	·81
100	— ·87	·60	·845
150	— ·88	·67	·905
200	·06	·81	·975
300	·17	·88	28·02
400	— ·02	·92	·06

Stat. 14. *V 12* (4.25—5.30).
66° 38′ N, 9° 30′ W.

M.	t° C.	S ‰	σt
0	—0·4	34·59	27·815
25	— ·29	·60	·815
50	— ·82	·64	·875
75	—1·19	·66	·905
100	— ·11	·69	·925
150	—0·23	·83	28·00
200	0·43	34·91	28·03
300	·32	·94	·06
400	·14	·93	·06

Stat. 15. *V 13* (9.50—11.0).
67° 16′ N, 12° 14′ W.

M.	t° C.	S ‰	σt
0	—0·2	34·48	27·715
25	— ·67	·44	·715
50	—1·39	·61	·88
75	— ·67	·68	·935
100	— ·59	·73	·97
150	—0·64	·81	28·01
200	·35	·91	·035
300	·14	·91	·045
400	— .05	·94	·08
600	— ·34 } — ·37 }	·95	·105

Stat. 16. *V 14* (16.40—18.0).
67° 38′ N, 10° 15′ W.

M.	t° C.	S ‰	σt
0	0·4	34·50	27·695
»	·3	·63	·81
25	— ·89	·55	·81
50	—1·36	·62	·885
75	— ·64	·68	·935
100	— ·66	·70	·95
150	—0·85	·79	28.005
200	·25	·93	·005
300	·14	·94	· 07
400	— ·09	·94	·085

Stat. 17. *V 15* (12.0—13.55).
67° 27′ 5 N, 7° 43′ W.

M.	t° C.	S ‰	σt
0	0.0	34·66	27·85
25	1·94 } 1·92 }	·90	·925
50	0·36	·78	·93
75	·83	·87	·97
100	1·27	·94	28·00
150	·67	·98	·01
200	·27	·99	·04
300	0·73	·96	·045
400	·32 } ·36 }	·95	·065
600	— ·09	·95	·09

Stat 18. *V 15.* (22.50—24.0).
67° 33′ N, 4° 49′ W.

M.	t° C.	S ‰	σt
0	4·0	34·97	27·79
25	3·92	35·01	·825
50	·35	·02	·885
75	·01	·04	·935
100	2·94	·03	·945
150	·73	·05	·97
200	·57	·05	·985
300	·58	·04	·98
400	1·87	34·98	·995

Stat. 19. *V 16* (9.15—10.0).
67° 40′ N, 2° 00′ W.

M.	t° C.	S ‰	σt
0	4·2	35·10	27·87
25	4·29	·00	·78
50	3·63	34·98	·83
75	·10	·96	·86
100	·12	·98	·885
150	3·08	35·00	27·90
200	2·71	·00	·945
300	·27	34·97	·96
400	1·80	·97	·995

Stat. 20. *V 16* (20.0—22.35).
67° 21′ 6 N, 0° 56′ E.

M.	t° C.	S ‰	σt
0	6·5	35·19	27·655
25	·66	·16	·605
50	·63	·16	·61
75	·33	·15	·645
100	·20	·15	·66
150	5.84	·12	·69
200	5·41	35·09	27·72
300	4·16	34·99	·785
400	2·83	·94	·875
600	0·68	·92	28·02
1000	— ·64 } — ·63 }	·92	·09

Stat. 21. *V 17* (7.0—8.0).
67° 29′ 6 N, 3° 52′ E.

M.	t° C.	S ‰	σt
0	5·9	35·17	27·73
25	·89	·14	·705
50	.77	·15	·725
75	5·28	35·09	27·735
100	·02	·09	·77
150	4·72	·08	·79
200	·56	·09	·82
300	3·73	·02	·845
400	2·70	34·99	·935

Stat. 22. *V 17* (15.0—16.0).
67° 36′ N, 6° 57′ E.

M.	t° C.	S ‰	σt
0	6·7		
25	·45	35·14	27·63
50	·22	·12	·64
75	·12	·11	·65
100	·02	·12	·67
150	5·59	·11	·715
200	·41	·10	·73
300	·13	·11	·77
400	3·45	·00	·865

Stat. 23. *V 17* (22.0—23.25).
67° 42′ N, 8° 55′ E.

M.	t° C.	S ‰	σt
0	6·2	34·68	27·29
25	·15	·71	·325
50	·14	·94	·51
75	·29	35·08	·60
100	·19	·09	·625
»	·23	·08	·61
150	·12	·12	·655
200	5·96	·11	·67
300	·80	·11	·69
400	·50	·10	·72
»	·52	·10	·72
600	3·46	·02	·875

Stat. 24. *V 18* (3.0—4.10).
67° 44′ N, 10° 35′ E.

M.	t° C.	S ‰	σt
0	5·5	34.44	27·195
10	·48	·45	·205
25	·25	·46	·24
50	·39	·56	·315
75	·05	·62	·40
100	·14	·69	·425
110	·28	·70	·425
135	·63	·83	·485
165	·94	35·00	·59

Table III.

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
Capella, Capt. A. Støkken, of Sandefjord. **1901.**									
	N	E				N	W		
III 8, 12	59° 15′	4° 26′	4·6		VI 17, 12	73° 0′	9° 53′	— 0·3	34·19
17			5·5		16	4′	8° 35′	0·0	33·77
22	50′	6′	4·4		23	10′	7° 25′	0·4	·95
III 9, 3.30			4·7		VI 24, 8	74° 20′	0′	0·1	34·01
6.30	60° 36′	3° 35′	6·2		10.30			0·5	·25
9			6·9		13	14′	4° 48′	0·6	·44
12	61° 18′	0′	7·4		16			0·4	·80
15			6·3		20	5′	2° 16′	0·4	·81
18			7·5		24			0·3	·83
23	62° 18′	20′	7·0		VI 25, 6	73° 55′	0° 16′	0·8	·86
III 10, 5.30			6·7		9.30			1·1	·77
12	63° 4′	16′	6·5				E		
17			6·3		13	51′	2° 5′	1·3	·80
20	44′	36′	6·3		16			1·4	·69
23			6·4		22	40′	4° 20′	1·9	
III 11, 2	64° 30′	4° 52′	6·5		VI 26, 3.30			1·9	
5.30			5·7		7	25′	6° 40′	3·2	·74
8	65° 18′	5° 10′	5·2		10			3·5	·72
18			6·4		14	19′	8° 28′	4·1	·89
III 12, 5			5·8		20			4·1	·81
11	57′	39′	6·1		24	4′	10° 24′	4·9	35·04
17			6·1		VI 27, 3.30			6·1	·18
21	66° 44′	20′	5·4		7.30	72° 45′	12° 36′	6·3	·14
24			5·3		10			6·9	·03
III 13, 3	67° 21′	4° 50′	5·8	35·17	13	24′	14° 40′	7·0	34·93
7			5·5	·20	15.15			7·3	33·91
15	55′	12′	4·6	·17	17.45	0′	16° 35′	6·8	34·95
19			4·5	·09	20.15			7·0	·88
22.30	68° 35′	3° 28′	4·0	·15	23	71° 45′	18° 39′	6·6	
III 14, 2			3·3	·17	VI 28, 2			6·5	35·01
5	69° 21′	2° 35′	4·0	·14	6.30	25	20° 25′	6·4	34·96
8			4·7	·12	12	18	21° 38′	6·7	·71
12	70° 6′	1° 40′	4·0	·07	VII 2, 24	71° 21′	25° 38′	6·4	·01
15.30			3·8	·11	VII 3, 4			7·0	·66
18	41′	0° 1′	3·3	·10	7	53′	26° 0′	6·6	·43
		W			10.30	72° 6′	27° 0′	6·5	·85
20.30			0·2	34·49	14			6·3	·86
12	71° 17′	0° 20′	1·0	·60	18	28′	29° 9′	5·4	·84
III 15, 7			— 0·9	·40	23			5·5	·77
		E			VII 4, 3.30	35′	31° 10′	4·2	·91
III 16, 12	72° 15′	1° 55′	2·0	·99	8			5·2	·70
17			2·5	35·07	14	45′	33° 10′	3·3	·72
III 17, 4	54′	2° 57′	0·9	·03	18			4·0	·89
		W			21.30	73° 10′	34° 52′	3·0	60
IV 18, 12	71° 38′	7° 12′	— 1·5	34·65	VII 5, 1			0·2	·52
17			— 1·7	·62	7	14′	36° 50′	1·8	
24	72° 14′	8° 0′	— 1·7	·84	12	18′	37° 50′	1·4	·01
IV 19, 8			— 1·4	·94	16			1·0	33·99
12	73° 9′	16′	— 1·7		20	35′	38° 46′	0·4	·52
IV 20, 20			— 1·5		24			0·1	·31
IV 21, 2	48′	9° 29′	— 1·8		VII 6, 4	35′	41° 0′	0·3	·30
6			— 1·8		7.30			0·5	·11
12	74° 31′	37′	— 1·7	34·78	12	34′	44° 7′	0·9	·77
16			— 1·6	·69	16	46′	51′	0·6	73
IV 22, 8	75° 11′	7′	— 1·7	·80	20			0·3	·74
V 13, 10	44′	4° 40′	— 1·2	·73	24	74° 11′	46° 20′	0·2	·64
22			— 1·5	·69	VII 7, 4			0·2	·87
V 14, 4	18′	5° 50′	— 1·6	·87	8	34′	47° 40′	— 0·9	·42
10			— 1·1	·87	16	43′	8′	— 0·6	·36
15	74° 37′	6° 50′	— 1·6	·69	VII 8, 18	26′	48° 10′	— 0·5	·52
20.30			— 1·5	·81	VII 12, 15	77° 0′	50′	0·9	34·58
V 15, 2	73° 45′	42′	— 1·6	·75	19			0·7	·52
8	37′	5° 15′	— 1·6	·87	23	35′	50° 5′	0·9	·51
V 16, 16	18′	4° 44′	— 1·3	·78	VII 13, 3			1·2	·61
VI 17, 8	72° 46′	10° 45′	— 0·9	·16	7.30	78° 10′	51° 11′	1·2	·59

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	E				N	E		
VII 13, 12	78° 29′	52° 7′	1·5	34·52	VIII 8, 2	69° 13′	8° 13′	9·5	35·05
16	48′	53° 20′	1·6	·49	5			9·5	·01
21	79° 12′	54° 30′	1·8	·22	8	1′	7° 0′	9·4	·07
VII 14, 1	35′	30′	1·6	·36	11			9·6	·04
VII 31, 12	75° 11′	41° 36′	— 0·2	32·65	14	68° 45′	6° 0′	10·4	·09
17			0·7	·95	17			10·5	·05
22	74° 52′	39° 38′	1·1	33·12	22	5′	5° 10′	10·4	·12
VIII 1, 5			1·2	·21	VIII 9, 7			10·4	·11
11	25′	37° 45′	1·7	·39	12	67° 35′	2° 55′	10·5	·12
15.30			2·0	·37	18			10·8	·12
20	6′	36° 0′	2·7	34·82	23	0′	3° 26′	11·5	·09
24			3·9	35·06	VIII 10, 6			11·4	34·95
VIII 2, 4	73° 44′	34° 17′	4·6		10.30	66° 23′	4° 0′	11·4	35·05
7.30			5·5	34·85	14.30			11·4	·09
10	19′	32° 0′	6·2	·88	18	65° 55,	3° 44′	11·3	·02
13			6·6	·72	22			12·0	34·89
19.30	0′	29° 30′	6·4	·50	VIII 11, 1.30	28′	20′	12·2	·82
23			6·6	·66	5.30			11·1	35·15
VIII 3, 4	72° 37′	27° 50′	7·1	·88	9.30	64° 45′	2° 33′	11·0	·10
10.30			7·6	·91	13			11·9	·16
13	16′	25° 40′	7·4	·85	16	28′	24′	12·2	
15.15			7·7	·75	18.15			11·7	
17.15	0′	23° 34′	7·6	·75	20.30	63° 46′	19′	11·8	
19.15			7·6	·66	23			12·0	
23.15	71° 48′	21° 50′	8·0		VIII 12, 2.30	0′	10′	12·4	
VIII 4, 12	54′	20° 48′	8·0	·87	8			11·6	
20			8·0	·89	12	62° 5′	0° 40′	12·4	
24	40′	19° 20′	8·2	·92	15.30			12·0	
VIII 5, 3			8·2	·77	18.30	61° 25′	40′	12·7	
6	71° 20′	17° 37′	9·1	·62	22			12·7	
9.30			8·8	·65	VIII 13, 5	60° 52′	40′	13·5	
14.30	0′	16° 0′	9·5		9			13·5	
20			9·2	35·02	14	20′	28′	14·0	
VIII 6, 8	9′	14° 0′	9·0	34·96	19.30			14·0	
16			9·0	35·02	VIII 14, 1	59° 50′	1° 20′	14·1	
20	70° 35′	12° 53′	8·4	·04	7			14·6	
24			7·6	·07	13	40′	2° 26′	14·8	
VIII 7, 5.30			9·1	·24	20			15·2	
12	9′	10° 48′	10·0	·10	VIII 15, 1.30	5′	3° 20′	15·9	
16			9·8	·07	8			17·0	
19.30	69° 48′	9° 10′	8·6	·08	12	58° 23′	4° 15′	17·0	
23			8·9	·07					
S/S Egil, Capt. HAUELAND, of Bergen. **1901.**									
	N	E				N	W		
IX 1, 12	60° 50′	3° 55′	12·6	34·56	IX 16, 12			11·2	0·20
16	56′	10′	12·2	35·28	IX 21, 20			8·0	34·05
20	61° 3′	2° 16′	13·0	·02	24	64° 32′	12° 51′	8·8	35·01
24	7′	1° 21′	11·8	·17	IX 22, 4	16′	10′	9·4	34·87
IX 2, 4	12′	0° 27′	11·2	·33	8	63° 59′	11° 28′	9·2	·56
		W			12	41′	10° 55′	7·8	·54
8	16′	0° 29′	11·6	·17	16	26′	10′	6·8	·25
12	19′	39′	11·0	·25	20	8′	9° 27′	8·8	·92
16	24′	1° 46′	10·8	·07	24	62° 49′	8° 45′	10·4	35·29
20	29′	2° 52′	10·0		IX 23, 4	35′	10′	10·8	·09
24	39′	3° 58′	9·8		IX 24, 4	0′	6° 35′	10·0	·08
IX 3, 4	50′	5° 3′	9·7	·25	6	61° 53′	7′	10·4	·07
8	62° 0′	6° 10′	10·4	·20	8	49′	5° 39′	10·2	·17
IX 4, 16	40′	8° 23′	10·6		10	44′	16′	10·2	
20	59′	9° 14′	10·6	·12	12	41′	4° 53′	10·4	·17
24	63° 19′	10° 10′	10·0	34·81	14	38′	18′	10·6	·05
IX 5, 4	38′	11° 3′	9·2	·73	16	36′	3° 42′	10·6	·08
8	57′	46′	8·8	·81	18	31′	30′	10·6	·11
12	64° 16′	12° 48′	7·2	·69	20	26′	7′	10·4	34·96
18			6·8		22	23′	2° 40′	10·6	35·08
IX 15, 12			9·0	32·90	24	20′	12′	10·6	·27
16			8·2	34·27	IX 25, 2	17′	1° 42′	10·9	·33

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	W				N	E		
IX 25, 4	61° 14′	1° 11′	11·5	35·21	IX 25, 16	60° 59′	1° 34′	12·2	34·94
6	11′	0° 44′	11·6	·29	18	56′	2° 6′	12·2	·99
8	9′	14′	11·8	·23	20	54′	36′	12·2	·98
		E			22	52′	3° 7′	12·2	32·32
10	7′	0° 13′	11·8	·29	24	50′	30′	13·0	·41
12	4′	40′	12·0	·27	IX 26, 2	47′	53′	13·0	34·04
14	1′	1° 6′	12·1	·06	4	44′	4° 16′	13·8	·05
Hekla, Capt. A. Marcussen, of Sandefjord. **1901.**									
	N	E				N	W		
III 8, 16	57° 28′	7° 0′	2·2	31·79	IV 20, 8	72° 50′	4° 49′	— 1·2	34·89
20	35′	6° 42′	4·2	33·70	16	73° 33′	3° 57′	— 1·2	·87
III 9, 2	45′	16′	5·0	34·25	IV 21, 20	4′	32′	— 1·5	·81
8	52′	5° 53′	4·7	33·86	IV 22, 22	72° 58′	2° 40′	— 1·2	·84
12	58° 44′	4° 6′	4·2	·96	IV 23, 7	35′	19′	— 1·7	·35
15	59° 2′	3° 48′	6·2	34·83	IV 24, 11	32′	1° 42′	— 1·7	17·18
18	20′	30′	6·2	·68	23	58′	53′	— 1·5	34·78
21	38′	12′	6·7	35·00	IV 25, 4	73° 11′	10′	— 1·5	·83
24	53′	2° 56′	6·2	34·66	13	23′	0° 21′	— 1.5	·81
III 10, 4	60° 9′	40′	6·2	35.08			E		
8	25′	24′	6·0	·05	18	73° 13′	0° 40′	— 1·5	34·83
10.30	44′	13′	6·0	34·90			W		
11	61° 4′	1° 56′	7·0	35·34	IV 26, 12	73° 39′	0° 2′	— 1·2	34·89
15.30	20′	46′	7.2	·23			E		
18	37′	44′	6·5	34·80	23	72° 57′	0° 39′	— 1·7	34·84
20	51′	39′	6·5	35·16	IV 27, 4	44′	1° 22′	— 1·5	·53
23	62° 15′	37′	6·5	·30	8	31′	58′	— 1·0	·41
III 11, 3	36′	33′	6·5	·33	IV 28, 8	70° 56′	2° 41′	3·7	35·17
11	63° 20′	30′	6·2	·23	12	29′	3° 21′	4·0	·11
20	34′	33′	6·2	·24	20	7′	1° 55′	5·0	·20
24	50′	29′	6·7	·23	24	2′	0° 53′	4·0	·17
III 12, 7	64° 8′	46′	6·5	·24			W		
15	15′	33′	6·5	·24	IV 29, 18	69° 52′	2° 39′	3·2	35·07
18	30′	18′	6·5	·24	IV 30, 12	43′	4° 21′	2·7	·00
20	46′	4′	6·0	·12	16	33′	5° 15′	3·2	·04
22,30	65° 0′	0° 53′	6·0	·15	20	25′	6° 0′	3·0	34·98
III 13, 2.30	17′	40′	5·7	·10	V 1, 4	20′	54′	0·7	·63
12	66° 3′	12′	5·5	·17	12	17′	7° 30′	— 0·2	·49
	N	W			16	7′	52′	0·7	·70
24	66° 30′	0° 7′	5·2	35·24	20	68° 53′	8° 16′	1·0	·84
III 14, 4	48′	23′	5·0	·17	V 2, 2	35′	10′	2·7	35·09
8	67° 7′	40′	5·0	·24	V 3, 4	15′	6° 28′	2·2	34·95
12	31′	1° 5′	5·0	·12	13	67° 56′	7° 12′	2·2	·98
14.30	49′	13′	4·2	·10	V 5, 6	68° 2′	8° 10′	1·2	·95
17.30	68° 0′	40′	4·2	·09	V 6, 12	14′	54′	0·5	·86
20	15′	2° 3′	4·2	·12	20	20′	9° 19′	0·5	·87
22	25′	21′	4·2	·10	V 7, 4	25′	39′	0·5	·87
III 15, 0.30	38′	38′	4·0	·14	V 10, 20	33′	56′	— 0·7	·72
3.30	46′	49′	4·0	·16	V 11, 1	22′	10° 15′	— 0·7	·72
7	69° 1′	3° 2′	3·5	·17	8	9′	40′	— 0·7	·68
10	20′	2° 51′	3·5	·16	V 16, 12	67° 31′	8° 41′	1·2	·65
13	38′	43′	3·5	·10	V 17, 17	0′	9° 13′	1·0	·44
16	59′	38′	3·5	·14	24	66° 45′	33′	1·0	·31
III 16, 12	70° 18′	27′	2·7	·21	V 18, 4	47′	10° 10′	1·5	·51
16	39′	16′	3·0	·18	12	48′	54′	0·7	·30
20	71° 5′	1° 58′	3·5	·16	18	58′	11° 39′	0·7	·30
24	59′	40′	3·0	·17	24	29′	12° 24′	1·0	·42
III 17, 4	72° 16′	23′	2·5	·12	V 19, 16	29′	45′	1·5	·32
12	30′	3′	2·5	·25	20	39′	13° 55′	1·7	·29
20	20′	45′	3·0	·22	V 20, 2	56′	14° 6′	0·7	·21
III 18, 8	10′	58′	1·5	·06	8	67° 2′	52′	0·5	·14
IV 18, 20	71° 31′	7° 6′	— 1·7	34·75	20	20′	15° 40′	0·7	·13
IV 19, 8	32′	6° 34′	— 1·7	·77	24	39′	16° 11′	0·5	·17
12	72° 6′	40′	— 1·7	·78	V 21, 8	40′	17° 2′	0·5	·17
16	22′	19′	— 1·7	·74	14	45′	51′	0·0	·02
20	38′	5° 58′	— 1·5	·89	20	52′	18° 49′	0·2	
24	41′	30′	— 1·5	·87	24	42′	19° 39′	0·2	·03

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	W				N	W		
V 22, 4	67° 39′	20° 19′	1·2	34·23	VII 19, 15	62° 32′	18° 4′	9·5	35·21
12	25′	41′	0·7	·03	21	28′	17° 21′	10·0	·19
20	28′	21° 23′	0·2	33·66	24	32′	16° 42′	10·0	·24
V 23, 8	24′	22° 16′	2·5	34·36	VII 20, 4	38′	15° 54′	10·0	·21
20	11′	23° 40′	1·2	·09	8	44′	10′	10·2	·21
V 27, 20	66° 30′	25° 12′	2·0	33·20	11	47′	14° 35′	10·2	·20
V 28, 12	27′	26° 17′	0·5	·27	17	55′	8′	10·5	·23
20	22′	27° 14′	0·5	·03	20	63° 2′	12° 43′	10·7	·24
VI 1, 12	65° 59′	28° 1′	6·5	35·18	VII 21, 8	6′	11° 52′	11·0	·25
VII 15, 20	40′	26° 3′	9·0	·01	12	4′	10° 34′	11·0	·13
24	24′	25° 42′	9·0	34·94	17	62° 58′	9° 58′	10·0	34·83
VII 16, 6	12′	31′	9·0	·99	24	56′	4′	10·0	35·03
13	64° 45′	12′	9·5	35·04	VII 22, 8	52′	8° 25′	10·0	·11
18	20′	10′	9·5	·01	19	48′	7° 44′	11·0	·14
24	5′	0′	9·5	·08	24	42′	6° 36′	10·7	·14
VII 17, 12	63° 40′	24° 32′	9·5	·07	VII 23, 4	36′	5° 51′	10·2	·16
20	25′	15′	8·7	·17	12	14′	4° 32′	10·5	·23
VII 18, 12	62° 57′	14′	9·7	·16	16	4′	3° 41′	11·0	·25
19	50′	23° 27′	9·7	·15	24	61° 47′	2° 31′	11·5	·14
22	43′	22° 40′	9·5	·14	VII 24, 4	40′	1° 56′	11·5	·14
VII 19, 3	38′	21° 50′	9·5	·16	8	30′	28′	11·7	·24
8	35′	20° 58′	9·7	·17	11	2′	0° 50′	13·0	·32
12	35′	19° 40′	9·5	·12					

Hvidfisken, Capt. FR. SVENDSEN, of Tromsø. **1901.**

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	E				N	E		
V 11, 12	70° 30′	19° 13′	5·5	34·18	VI 17, 8	75° 45′	9° 53′	1·6	34·78
24	71° 16′	17° 28′	5·3	·51	VI 19, 8	76° 19′	8° 55′	1·8	·74
V 12, 12	72° 15′	15° 4′	5·4	·94	VI 20, 12	44′	17′	1·8	·82
16	35′	14° 20′	4·8	35·10	VI 21, 12	57′	17′	2·1	·60
24	55′	13° 54′	4·3	·07	VI 22, 12	49′	9° 6′	2·1	·79
V 13, 12	73° 20′	11° 58′	4·1	·05	VI 24, 17	77° 15′	10° 44′	3·2	·95
V 14, 12	74° 2′	7′	2·5	·07	VI 25, 12	30′	11° 45′	2·4	·63
V 15, 12	73° 45′	10° 41′	3·1	34·99	VI 26, 16	9′	14° 19′	1·5	·54
24	30′	11° 29′	1·5	·78	VI 27, 20	35′	13° 57′	2·5	·26
V 16, 12	15′	59′	2·2	·97	VI 28, 8	33′	14° 47′	2·6	·25
V 17, 12	72° 52′	12° 5′	3·2	35·08	VII 1, 20	33′	15° 12′	5·0	25·02
V 18, 12	59′	58′	3·3	·03	VII 6, 20	33′	12′	6·3	24·02
V 19, 12	54′	9° 28′	2·5	·05	VII 15, 20	33′	12′	2·7	33·22
V 20. 12	44′	11° 21′	3·8	·14	VII 22, 20	33′	12′	3·8	32·67
V 21, 24	73° 19′	10° 13′	2·0	34·97	VII 28, 20	33′	12′	4·9	21·14
V 23, 12	26′	12° 23′	2·4	35·07	VIII 11, 20	33′	12′	3·0	33·06
V 25, 12	72° 37′	13° 49′	5·0	34·75	VIII 27, 20	33′	12′	3·5	32·00
V 26, 12	18′	28′	3·9	35·09	IX 10, 20	33′	14° 47′	2·7	33·16
V 27, 12	28′	10° 31′	2·9	34·99	IX 11, 20	35′	13° 18′	2·7	·70
V 28, 12	43′	9° 22′	2·2	·92	IX 12, 12	12′	12° 59′	2·9	·69
V 30, 12	73° 9′	43′	2·4	35·03	20	76° 56′	13° 10′	2·5	34·09
V 31, 12	59′	10° 24′	2·1	34·99	IX 13, 20	35′	12° 49′	4·4	34·82
VI 1, 12	74° 10′	12° 6′	2·5	35·02	IX 14, 20	75° 59′	14° 36′	5·7	35·00
VI 2, 12	73° 41′	4′	2·6	·05	IX 15, 8	20′	16° 18′	5·3	34·94
VI 3, 12	74° 2′	10° 52′	1·8	34·96	IX 16, 4	17′	18° 32′	3·4	·83
VI 4, 4	27′	8° 40′	1·2	·77	12	3′	19° 37′	2·9	·47
12	58′	9° 0′	1·8	·90	IX 17, 4	74° 32′	20° 10′	2·6	·36
24	75° 15′	45′	1·1	·73	16	13′	38′	2·6	·27
VI 5, 20	33′	8° 7′	1·2	·73	IX 18, 4	73° 54′	47′	4·6	·47
VI 6, 12	51′	35′	1·4	·73	16	27′	45′	6·5	·82
VI 7, 12	76° 15′	7° 43′	1·2	·66	20	2′	12′	7·7	·93
VI 8, 12	15′	8° 56′	1·6	·80	IX 19, 4	72° 15′	19° 55′	8·6	·97
VI 9, 12	11′	9° 26′	1·5	·84	8	71° 54′	48′	9·0	·90
VI 10, 12	22′	7° 8′	1·2	·65	12	36′	30′	9·0	·92
VI 11, 8	77° 1′	6° 21′	0·2	·70	IX 20, 6	5′	18° 46′	11·4	·51
20	26′	0′	1·1	·56	12	70° 46′	19° 11′	11·4	·57
VI 12, 12	33′	7° 8′	2·3	·65	20	30′	28′	11·4	33·74
24	18′	9° 58′	2·6	·78	IX 21, 4	21′	17° 50′	11·2	·65
VI 13, 12	76° 21′	10′	1·4	·76	16	69° 47′	42′	11·2	·59
VI 14, 20	75° 53′	19′	1·8	·74	IX 22, 8	31′	18° 25′	8·8	31·14

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
Jasai, Capt. INGV. SVENDSEN, of Tromsø. **1901.**									
	N	E				N	E		
V 11, 12	70° 29′	19° 35′	5·9	34·36	VIII 8, 16	74° 51′	13° 38′	5·6	35·03
17	46′	18° 54′	5·3	·58	20	47′	14° 2′	6·4	·05
V 12, 8	71° 50′	15° 31′	6·1	35·10	24	41′	36′	6·5	·10
16	72° 28′	2′	5·3	·10	VIII 9, 4	30′	13° 51′	6·0	·08
V 13, 12	73° 25′	12° 6′	4·4	·16	6	18′	39′	6·4	·11
18	32′	11° 42′	4·1	·05	8	3′	39′	6·0	·07
V 14, 16	52′	10° 31′	2·4	34·89	10	73° 49′	39′	6·3	·07
24	74° 0′	9° 30′	2·3	·97	12	40′	39′	7·3	·03
V 16, 4	18′	12° 50′	2·1	·42	16	32′	8′	8·3	34·99
V 17, 12	73° 48′	13° 55′	4·0	·99	20	23′	12° 42′	8·4	35·01
V 18, 24	74° 2′	11° 5′	2·5	35·08	22	18′	19′	7·8	·01
V 21, 12	17′	15′	2·0	34·86	24	14′	47′	8·4	·01
V 25, 4	73° 38′	13° 33′	2·3	35·10	VIII 10, 4	17′	13° 24′	8·4	34·96
12	32′	11° 58′	2·5	·10	8	15′	58′	8·4	35·01
V 27, 22	5′	8′	2·7	·03	12	18′	14° 41′	7·9	34·96
V 29, 12	33′	53′	2·5	·05	16	21′	15° 30′	7·5	·59
VI 4, 12	75° 7′	10° 56′	1·5	34·92	20	25′	16° 24′	7·4	29·26
VI 5, 8	18′	9° 48′	1·0	·87	24	15′	42′	7·5	35·03
VI 9, 12	17′	13° 57′	2·8	35·04	VIII 11, 4	2′	17° 6′	7·4	·03
VI 14, 12	74° 52′	11° 42′	2·1	34·84	8	72° 48′	26′	7·4	·01
VI 16, 12	75° 9′	12° 26′	2·1	·86	12	37′	21′	8·3	34·90
VI 18, 12	26′	3′	2·4	·85	15	20′	30′	8·4	35·34
VI 19, 4	76° 0′	11° 3′	2·4	·88	17	4′	34′	8·4	·01
VI 20, 12	30′	10° 49′	2·1	·85	19	71° 47′	39′	8·6	34·90
VI 21, 12	51′	4′	2·1	·78	21	35′	18° 16′	8·6	·73
20	77° 5′	11° 0′	3·5	·89	24	18′	28′	9·1	·78
VI 22, 12	76° 59′	9° 44′	2·7	·62	VIII 12, 2	3′	35′	9·1	·74
VI 24, 4	77° 25′	11° 40′	4·4	·66	4	70° 49′	41′	9·1	·51
12	42′	10° 58′	4·6	·60	8	35′	19° 0′	9·4	·57
VI 25, 8	48′	11° 45′	1·9	·54	12	49′	31′	9·6	·31
VI 26, 20	78° 8′	28′	1·3	·23	20	59′	20° 8′	9·3	·59
VII 4, 20	77° 42′	14° 42′	4·2	32·40	24	71° 8′	35′	9·2	·57
VIII 7, 12	22′	13° 15′	4·0	34·42	VIII 13, 4	70° 54′	48′	9·4	·18
15	4′	6′	5·7	35·01	8	35′	11′	9·5	·16
18	76° 43′	6′	5·8	·01	12	27′	6′	9·7	·02
21	26′	6′	5·8	·06	16	13′	22′	9·9	32·71
24	8′	6′	5·9	·10	20	1′	12′	8·9	·67
VIII 8, 4	75° 50′	6′	5·7	·06	24	69° 50′	19° 43′	8·7	·53
8	32′	6′	5·5	·00	VIII 14, 4	48′	27′	8·5	·56
12	74° 56′	15′	5·1	34·98	8	46′	9′	8·5	·99
Kvik, Capt. N. J. NILSEN, of Sandefjord. **1901.**									
	N	W				N	W		
IV 3, 12	61° 1′	2° 3′	6·4	35·18	IV 12, 20	63° 21′	3° 24′	5·8	35·12
16	62° 11′	2° 23′	6·5	·25	IV 13, 8	64° 43′	4° 34′	4·0	·03
IV 4, 8	27′	3° 7′	6·8	·33	12	65° 6′	4° 52′	3·5	34·95
16	12′	8′	6·2	·32	16	17′	5° 3′	3·0	·92
IV 5, 8	61° 36′	0′	7·5	·30	20	27′	13′	3·0	·94
12	22′	2° 40′	7·5	·32	IV 14, 8	52′	45′	2·2	35·03
IV 6, 8	45′	2′	7·0	·39	12	66° 25′	6° 13′	2·6	·03
18	52′	1° 10′	6·5	·29	16	44′	30′	2·8	34·99
IV 7, 8	62° 49′	2° 37′	5·0	·18	20	67° 1′	45′	1·8	·89
12	63° 15′	53′	4·9	·09	IV 15, 8	30′	7° 18′	0·2	(35·33)
18	35′	3° 22′	4·6	·12	IV 16, 16	42′	8° 5′	0·3	34·77
IV 8, 8	54′	40′	4·3	·04	IV 17, 8	43′	25′	−0·2	·71
16	64° 13′	4° 12′	3·9	34·98	20	45′	9° 20′	−0·5	·68
20	20′	27′	3·9	·97	IV 18, 8	10′	17′	−0·4	·56
IV 9, 8	14′	5° 29′	3·0	·92	20	42′	49′	−0·5	·67
16	6′	6° 12′	4·0	35·03	IV 19, 12	41′	13′	0·0	·79
IV 10, 8	10′	5° 12′	3·8	·03	IV 20, 8	50′	36′	0·2	·80
20	63° 47′	4° 36′	5·5	·19	16	68° 8′	40′	0·4	·74
IV 11, 8	25′	13′	5·0	·25	IV 21, 8	22′	0′	0·7	·78
16	1′	3° 52′	5·7	·20	IV 22, 8	69° 2′	8° 4′	1·2	·72
IV 12, 12	62° 51′	0′	6·0	34·75	16	68° 43′	35′	1·4	·90

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	W				N	W		
IV 23, 8	68° 21′	9° 24′	0·0	34·64	VI 9, 8	66° 51′	11° 45′	2·5	34·11
IV 24, 8	67° 49′	10° 14′	0·0	·67	20	51′	45′	2·9	·14
16	49′	9° 5′	0·5	·69	VI 10, 16	19′	12′	3·5	·24
IV 25, 8	68° 0′	7° 22′	1·7	·88	24	3′	10° 51′	3·8	·32
20	1′	21′	2·0	·93	VI 11, 8	65° 50′	32′	3·4	
IV 26, 8	67° 58′	49′	1·2	·80	16	44′	9° 35′	5·0	
16	44′	57′	1·6	·92	24	44′	8° 24′	5·0	
IV 27, 8	7′	8° 32′	0·5	·58	VI 12, 4	45′	5′	4·8	
IV 28, 8	6′	9° 11′	0·6	·57	12	43′	7° 23′	4·0	
16	2′	10° 24′	1·6	·67	20	33′	5′	4·5	34·86
IV 29, 8	2′	11° 46′	0·6	·16	VI 13, 8	13′	6° 53′	4·5	·81
20	3′	20′	1·0	·59	16	1′	46′	5·0	·86
IV 30, 8	12′	10° 30′	0·8	·50	VI 14, 8	3′	7° 5′	4·0	
16	34′	15′	0·5	·85	20	12′	6° 42′	5·0	
V 2, 16	34′	25′	0·5	·66	VI 15, 8	64° 56′	7° 20′	4·7	
V 3, 8	20′	9° 50′	0·7	·52	20	65° 2′	6° 37′	4·0	34·72
V 5, 16	13′	10° 27′	1·2	·51	VI 16, 8	64° 44′	7° 15′	5·5	·90
V 6, 8	16′	0′	1·2	·53	20	40′	6° 46′	5·0	·89
20	17′	40′	1·0	·46	VI 17, 8	35′	4′	5·6	·89
V 7, 8	7′	11° 39′	1·5	·82	VI 18, 8	48′	5° 54′	6·0	·91
V 9, 12	14′	9° 42′	1·0	·49	VI 19, 16	65° 6′	7° 0′	5·2	·75
V 10, 8	16′	11° 29′	1·5	(·34)	VI 21, 8	64° 51′	6° 55′	4·5	·67
V 11, 8	18′	10° 33′	1·4	·46	20	65° 5′	7° 22′	4·8	·71
V 12, 8	66° 53′	8° 24′	1·3	·56	VI 22, 12	26′	6° 21′	5·0	·81
16	68° 4′	0′	2·1	·88	VI 23, 8	18′	7° 19′	5·3	
20	40′	0′	3·0	·88	VI 24, 8	64° 20′	6° 38′	7·3	34·81
V 13, 8	55′	48′	3·0	·95	12	4′	31′	7·8	
20	69° 4′	9° 29′	1·5	·68	16	63° 48′	22′	9·5	
V 14, 12	12′	8° 56′	1·4	·63	VI 25, 12	19′	5° 44′	9·6	35·00
V 15, 8	52′	4′	0·6	·56	VI 26, 8	3′	4° 22′	9·5	·22
16	49′	6° 22′	1·4	·57	20	5′	0′	9·5	34·96
V 16, 16	41′	3′	3·8	·99	VI 27, 12	17′	2′	9·0	·96
V 17, 8	13′	5° 22′	4·0	35·02	20	62° 59′	3° 56′	9·4	35·15
V 18, 8	5′	6° 53′	3·0	34·93	VI 29, 16	63° 10′	4° 35′	9·8	
16	68° 38′	7° 29′	3·3	(·92)	24	12′	5° 21′	9·0	34·98
V 19, 8	29′	8° 24′	1·5	·72	VI 30, 8	14′	6° 40′	9·5	35·06
16	21′	9° 1′	1·6	·76	16	16′	7° 0′	10·0	·26
24	12′	10° 19′	0·2	·60	24	5′	44′	10·3	·20
V 20, 8	0′	11° 18′	0·2	·60	VII 1, 8	1′	8° 14′	10·5	·17
20	67° 58′	12° 16′	0·3	·61	20	5′	6° 45′	10·3	·15
V 21, 20	68° 1′	40′	1·0	·72	VII 3, 12	13′	18′	10·3	·05
V 22, 12	04′	2′	1·1	·42	VII 4, 12	40′	21′	10·2	·12
20	4′	14′	0·9	·56	20	25′	7° 10′	9·5	34·89
V 23, 12	67° 50′	33′	1·8	·54	VII 5, 8	16′	46′	11·0	35·12
V 24, 16	42′	0′	2·1	·37	16	8′	0′	11·0	·21
V 25, 8	39′	16′	2·0	·46	24	62° 50′	6° 55′	10·4	·12
V 26, 16	0′	12′	2·4	·14	VII 7, 12	63° 13′	5′	11·0	·22
V 28, 8	66° 48′	11° 45′	2·9	·35	VII 8, 8	4′	5° 24′	11·0	·19
20	53′	55′	2·8	·15	VII 9, 8	3′	4° 45′	11·5	
V 29, 20	67° 6′	12° 24′	3·0	·28	VII 10, 8	16′	5° 30′	11·0	35·19
V 30, 20	12′	40′	3·2	·39	24	62° 58′	36′	11·3	·14
V 31, 8	16′	40′	2·2	·44	VII 11, 12	50′	6° 12′	11·5	·23
20	18′	51′	2·0	·51	20	45′	7° 1′	11·4	(·20)
VI 1, 8	12′	52′	2·0	·50	VII 12, 4	36′	6° 17′	11·0	
VI 2, 8	22′	11° 58′	1·7	·41	12	38′	5° 34′	11·0	
20	2′	35′	2·3	·35	20	32′	4° 58′	10·3	35·16
VI 3, 16	3′	12° 12′	0·0	·32	VII 13, 4	24′	16′	10·7	
VI 4, 8	10′	10° 48′	0·5	·35	12	13′	3° 45′	11·0	35·15
20	16′	12′	0·7	·35	20	61° 58′	31′	11·0	·23
VI 5, 8	10′	11° 3′	0·8	·29	VII 14, 4	51′	24′	11·2	·20
20	26′	38′	0·9	·11	12	30′	2° 40′	11·8	·19
VI 6, 8	17′	10° 51′	0·7	·34	24	13′	26′	12·0	
20	13′	38′	1·2	·42	VII 15, 4	60° 52′	45′	12·5	
VI 7, 8	4′	20′	1·5	·43	12	45′	3° 9′	12.3	·19
20	66° 44′	9° 33′	1·9	·45	20	45′	1° 51′	12·9	·40
VI 8, 20	55′	11° 3′	2·3	·17					

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
Urania, Capt. CHR. LARSEN, of Aalesund. **1901.**									
	N	W				N	W		
V 2, 18.30	63° 27′	1° 8′	9·0	35·25	VI 17, 22	65° 10′	7° 0′	5·5	34·86
V 4, 18	8′	33′	8·0	·13	VI 18, 18	19′	6° 22′	5·5	·86
V 5, 18	55′	32′	8·0	·25	VI 26, 17	5′	0′	8·0	35·04
V 11, 16	64° 46′	4° 42′	6·0	·04	VI 28, 17.30	0′	45′	7·5	34·83
V 12, 8	65° 27′	5° 47′	5·0	34·96	VII 3, 21	12′	5° 45′	9·0	·89
17	53′	6° 22′	3·0	·79	VII 7, 13	64° 42′	6° 38′	9·0	·96
V 13, 17.30	66° 30′	7° 46′	2·0	·66	24	33′	5° 56′	9·7	·98
V 14, 21	42′	8° 46′	2·0	·79	VII 8, 13	12′	0′	10·7	35·15
V 16, 16.30	40′	10° 19′	1·0	·34	22	2′	4° 16′	10·0	·04
V 17, 22	67° 19′	11° 16′	0·5	·31	VII 10, 20	63° 50′	5° 34′	10·0	34·96
V 21, 11	52′	10° 54′	0·0	·60	VII 11, 13	30′	44′	10·8	35·17
V 24, 20.30	34′	9° 12′	1·5	·54	VII 14, 17.30	62° 58′	20′	10·8	·08
VI 3, 23	48′	12° 18′	2·0	·66	VII 15, 10	53′	6° 2′	10·8	·05
VI 4, 9	50′	58′	2·0	·51	VII 17, 17	63° 4′	2° 30′	11·0	·15
VI 10, 23	40′	11° 20′	2·8	·34	24	62° 59′	1° 20′	12·8	·20
VI 13, 23	66° 58′	8° 50′	3·0	·61			E		
VI 14, 10	28′	0′	3·5	·87	VII 18, 11	48′	0° 33′	12·0	·18
VI 15, 17.30	65° 49′	7° 30′	3·8	·68	22	45′	2° 30′	12·8	·07
VI 16, 17	27′	17′	4·8	·82					
Aksel, Capt. N. J. NIELSEN, of Sandefjord. **1902.**									
	N	W				N	W		
IV 14, 12	61° 48′	2° 48′	7·5	35·34	V 13, 20	63° 15′	4° 59′	5·9	35·24
20	56′	3° 0′	7·6	35	V 14, 8	14′	5° 28′	6·6	·32
IV 15, 8	62° 7′	33′	6·0	·34	20	24′	6° 10′	6·0	·17
16	15′	50′	7·1	·46	V 15, 4	36′	34′	5·9	·23
IV 16, 8	29′	45′	6·6	·26	12	52′	55′	5·5	·17
IV 19, 8	46′	0° 58′	6·7	·35	20	64° 6′	7° 33′	3·1	34·89
20	45′	1° 33′	6·8	·25	V 16, 4	12′	8° 11′	2·7	·87
IV 20, 8	35′	2° 3′	6·7	·29	12	21′	43′	5·2	35·04
20	31′	28′	6·8	·37	20	36′	9° 12′	5·1	·05
IV 21, 8	37′	13′	6·9	·23	V 17, 4	49′	45′	4·2	34·77
20	43′	20′	6·8	·35	16	50′	26′	5·6	35·06
IV 22, 8	36′	51′	6·9	·26	V 18, 4	48′	8° 23′	2·9	34·75
IV 23, 8	46′	4° 12′	7·1	·28	12	36′	18′	4·7	·95
20	50′	23′	7·2	·26	20	45′	7° 50′	0·7	·67
IV 24, 8	63° 4′	50′	7·3	·25	V 19, 4	65° 2′	27′	2·6	·91
IV 25, 8	10′	38′	7·3	·26	12	64° 51′	11′	3·4	·97
20	62° 54′	38′	7·3	·28	20	65° 0′	6° 41′	2·7	·91
IV 26, 8	58′	30′	7·3	·24	V 20, 8	1′	7° 10′	1·1	·73
IV 27, 12	42′	2° 34′	7·5	·25	20	8′	19′	1·3	·73
IV 28, 10	27′	25′	7·5	·31	V 21, 4	22′	45′	0·7	·65
20	20′	18′	7·2	·26	12	56′	8° 10′	0·8	·62
IV 29, 20	22′	20′	6·9	·17	20	66° 15′	20′	0·3	·72
IV 30, 18	15′	0° 59′	7·0	·25	24	27′	9° 23′	0·6	·50
V 1, 8	15′	1° 35′	6·2	·22	V 22, 8	38′	10° 8′	0·3	·50
V 2, 20	15′	55′	6·7	·24	16	44′	15′	0·4	·38
V 3, 4	27′	2° 40′	7·9	·40	20	49′	23′	0·2	·34
8	43′	55′	7·9	·31	24	57′	39′	0·1	·57
20	47′	24′	7·9	·30	V 23, 4	67° 1′	49′	— 0·4	·66
V 4, 8	27′	1° 53′	7·2	·28	12	48′	11° 8′	— 0·1	·65
V 5, 8	20′	59′	8·1	·35	V 24, 8	45′	12′	0·1	·61
V 6, 12	14′	54′	8·4	·34	20	31′	57′	— 0·1	·59
V 7, 12	23′	3° 20′	8·1	·33	V 25, 8	36′	12° 35′	— 0·3	·63
V 8, 12	26′	2° 2′	7·5	·35	16	38′	6′	— 0·2	·63
V 10, 12	47′	33′	7·4	·26	V 26, 8	27′	11° 12′	0·3	·40
20	50′	28′	5·9	·13	20	43′	44′	— 0·4	·62
V 11, 12	63° 6′	3° 53′	6·9	·26	V 27, 8	45′	29′	— 0·6	·68
V 12, 8	62° 59′	58′	6·8	·29	20	35′	10° 53′	0·2	·43
20	63° 8′	40′	6·0	·19	V 28, 8	27′	4′	0·3	·47
V 13, 8	9′	4° 5′	6·9	·24	20	12′	9° 44′	— 0·1	·42

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	W				N	W		
V 29, 8	67° 8′	9° 12′	— 0·1	34·46	VI 20, 20	63° 46′	4° 40′	7·1	35·12
20	5′	8° 57′	— 0·3	·48	VI 21, 4	64° 14′	5° 10′	6·2	·10
V 30, 8	10′	45′	— 0·2	·47	12	65° 0′	4° 42′	6·3	·05
20	27′	9° 24′	— 0·3	·48	20	2′	5° 29′	5·6	·01
V 31, 8	1′	11° 23′	— 0·1	·43	VI 22, 4	3′	6° 33′	4·4	34·98
20	21′	12° 6′	0·0	·42	12	4′	7° 0′	3·9	·82
VI 1, 8	36′	11° 38′	0·1	·59	24	64° 45′	16′	3·7	·78
20	48′	41′	0·1	·67	VI 23, 12	28′	26′	4·1	·65
VI 2, 8	68° 10′	12° 10′	— 0·3	·75	20	13′	18′	4·3	·88
VI 3, 8	2′	11° 55′	0·0	·73	VI 24, 4	63° 44′	9′	4·9	·79
20	0′	26′	0·9	·78	20	24′	12′	7·9	35·33
VI 4, 8	67° 48′	10° 42′	0·5		24	35′	6° 43′	4·5	34·68
16	39′	10′	1·1	·85	VI 25, 20	43′	8′	5·2	·74
VI 5, 8	26′	9° 43′	0·7	·59	VI 26, 12	48′	5° 28′	7·0	·94
20	20′	24′	0·6	·67	VI 27, 8	19′	4° 46′	7·0	·95
VI 6, 8	0′	7° 45′	2·7	·96	12	45′	10′	7·7	35·01
20	66° 49′	6° 45′	2·3	·89	20	31′	3° 56′	8·1	·35
VI 7, 8	21′	11′	4·1	·98	VI 28, 8	15′	38′	7·6	·14
20	0′	36′	3·9	35·02	20	2′	4° 2′	8·4	·26
VI 8, 8	65° 52′	7° 35′	1·6	34·74	VI 29, 12	7′	32′	8·6	·44
16	37′	27′	3·1	·92	24	17′	5° 19′	6·6	34·91
VI 9, 12	23′	6° 56′	2·6	·83	VI 30, 4	21′	3′	6·3	·87
VI 10, 8	17′	25′	4·2	35·00	24	13′	34′	6·1	35·02
VI 11, 12	21′	20′	4·5	·01	VII 1, 8	11′	6° 13′	5·4	34·73
20	14′	7′	4·5	·02	VII 2, 12	8′	5° 32′	5·3	·58
VI 12, 8	8′	4′	4·4	·01	VII 3, 8	0′	6° 2′	6·5	·81
VI 13, 8	4′	5° 54′	5·3	·03	12	2′	22′	5·9	·78
20	0′	44′	4·9	·02	20	12′	40′	8·2	35·23
VI 14, 8	64° 32′	49′	5·3	·04	VII 4, 8	62° 58′	30′	6·6	34·82
12	16′	49′	5·8	·07	VII 5, 8	63° 5′	5° 50′	6·8	·82
20	63° 55′	44′	5·3	·03	VII 6, 8	20′	6° 0′	7·3	·85
VI 15, 8	41′	4° 46′	6·8	·18	20	10′	20′	6·2	·65
16	42′	28′	6·2	·11	VII 7, 8	21′	7° 10′	7·8	35·17
VI 16, 8	58′	6° 0′	4·9	34·96	20	62° 54′	8° 10′	8·8	·30
16	64° 7′	31′	5·6	35·01	VII 9, 8	63° 12′	6° 30′	8·0	·02
VI 17, 12	22′	42′	5·3		20	62° 54′	40′	7·5	34·80
22	1′	7° 3′	5·7	·02	VII 10, 8	63° 0′	52′	9·1	35·31
VI 18, 4	63° 43′	5′	5·0	34·92	16	8′	10′	8·9	·28
9	25′	5′	7·9	35·31	VII 11, 8	62° 48′	20′	6·2	34·42
12	62° 54′	6° 30′	8·0	·37	20	63° 12′	0′	7·1	·83
20	63° 2′	5° 50′	7·9	·28	VII 12, 12	62° 58′	5° 50′	7·9	·87
VI 19, 4	1′	10′	7·9	·35	VII 13, 8	63° 4′	6° 0′	7·2	·78
12	0′	4° 16′	8·1	·32	VII 14, 20	62° 50′	0′	7·4	·89
20	3′	4′	8·2	·33	VII 15, 20	24′	4° 51′	8·5	35·07
VI 20, 8	28′	23′	7·8	·31	VII 16, 8	37′	3° 13′	9·8	·13

Hvidfisken, Capt. FR. SVENDSEN, of Tromsø. **1902.**

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	E				N	E		
V 13, 20	70° 4′	19° 40′	4·0	34·38	V 25, 20	73° 19′	11° 5′	3·9	35·14
V 16, 22	34′	22′	4·5	·48	V 26, 12	41′	9° 22′	2·1	34·94
V 17. 16	71° 7′	18° 19′	5·3	·91	20	45′	8° 15′	0·2	·78
12	28′	17° 41′	6·0	35·18	V 27, 12	57′	11° 29′	3·8	35·11
20	38′	6′	5·7	·08	V 28, 12	50′	50′	3·8	·03
V 18, 4	54′	16° 12′	5·6	·08	24	74° 9′	6′	2·8	·14
12	72° 10′	14° 52′	5·4	·14	V 30, 12	72° 59′	10° 22′	3·5	·11
20	16′	13° 7′	5·4	·05	V 31, 12	33′	53′	3·2	·14
V 19, 12	22′	12° 51′	5·4	·18	VI 1, 12	73° 28′	12° 27′	4·0	·15
V 20, 4	33′	1′	5·0	·15	20	50′	10° 30′	3·3	·12
12	32′	11° 25′	4·3	·15	VI 2, 12	74° 13′	9° 41′	2·7	·04
V 21, 8	14′	9° 49′	4·0	·17	VI 3, 4	39′	20′	2·2	·04
20	0′	14′	3·9	·17	20	50′	38′	2·3	·05
V 22, 12	2′	10° 28′	4·3	·17	VI 4, 12	49′	8° 55′	2·3	·04
V 23, 12	37′	14′	4·0	·15	VI 5, 4	58′	10° 38′	1·6	·02
20	73° 5′	14′	4·2	·15	12	75° 19′	46′	2·2	·03
V 24, 4	26′	2′	3·9	·10	VI 6, 8	28′	30′	3·0	·08
23	11′	11° 15′	3·7	·00	VI 7, 4	30′	8° 2′	2·0	·23

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	E				N	E		
VI 8, 12	75° 35′	9° 0′	2·3	35·05	VI 20, 12	76° 43′	7° 35′	3·7	34·73
VI 9, 4	40′	20′	2·5	·05	VI 21, 20	40′	8° 32′	3·5	·66
12	22′	8° 10′	1·3	34·94	VI 25, 20	45′	9° 38′	5·0	·12
VI 11, 4	33′	10° 25′	2·3	35·05	VI 26, 12	77° 2′	8° 28′	4·7	·33
VI 12, 12	26′	9° 40′	2·7	·04	VI 27, 20	76° 56′	5′	4·8	33·81
VI 13, 12	24′	9° 1′	3·3	·07	VI 28, 12	49′	9° 9′	5·0	·68
VI 14, 12	17′	7° 42′	2·8	·04	VI 29, 12	77° 39′	12° 0′	2·0	34·24
VI 15, 12	31′	8° 29′	2·5	·04	24	78° 11′	14° 0′	1·3	·06
VI 16, 12	48′	9° 45′	2·7	·06	VI 30, 24	7′	12° 34′	2·9	·16
VI 18, 12	55′	20′	1·7	34·86	VII 3, 20			0·4	·25
VI 19, 12	76° 13′	56′	2·4	·88					

Rivalen, Capt. H. ANDRESEN, of Tromsø. **1902.**

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	E				N	E		
V 29, 20	72° 10′	19° 20′	5·0	34·90	VIII 1, 24	77° 5′	14° 0′	3·0	33·22
V 30, 8	73° 0′	20° 10′	5·0	35·17	VIII 3, 18	20′	13° 40′	2·5	32·97
12	25′	30′	4·0	·17	VIII 4, 8	50′	12° 20′	6·0	34·38
16	45′	40′	4·0	·17	24	78° 20′	9° 50′	5·0	·05
V 31, 8	74° 0′	10′	4·0	·17	VIII 5, 12	79° 30′	10° 20′	5·0	33·76
24	10′	19° 40′	3·5	·17	VIII 6, 12	52′	11° 0′	4·0	34·04
VI 1, 6	30′	20° 0′	2·5	·15	VIII 13, 20	55′	10° 50′	4·0	·00
12	45′	21° 10′	1·5	·04	VIII 15, 20	50′	13° 0′	2·5	33·15
20	30′	23° 10′	— 1·0	·18	VIII 16, 20	45′	12° 45′	3·5	·91
VI 3, 12	50′	20° 0′	0·0	34·92	VIII 19, 18	55′	13° 0′	3·0	·47
VI 4, 20	75° 10′	18° 15′	1·2	·77	VIII 23, 20	80° 30′	18° 30′	— 0·5	·34
VI 8, 24	30′	17° 10′	— 1·0	·96	VIII 28, 22	0′	20′	3·5	·06
VI 11, 20	20′	15° 50′	0·0	33·69	VIII 31, 12	79° 48′	12° 50′	4·5	·49
VI 17, 18	10′	16° 40′	2·2	·98	IX 3, 24			4·0	·10
VI 18, 8	25′	17° 10′	2·2	·58	IX 6, 18	8′	9° 25′	2·0	32·72
VI 20, 12	50′	30′	— 0·5	35·21	IX 7, 6	78° 50′	7° 30′	2·5	33·56
VI 21, 20	74° 50′	16° 40′	1·5	34·11	IX 9, 8	30′	8° 20′	4·5	34·59
VI 28, 16	75° 0′	17° 0′	1·0	35·26	16	10′	30′	5·0	35·05
VII 1, 8	30′	0′	3·0	34·26	IX 10, 8	77° 40′	11° 0′	2·0	33·86
VII 3, 20	74° 11′	10′	2·0	·13	IX 11, 20	30′	12° 20′	0·0	34·04
VII 5, 20	73° 50′	30′	1·0	32·78	IX 12, 8	10′	12° 0′	3·0	35·08
VII 7, 18	55′	20′	2·2	33·57	IX 13, 8	76° 50′	15′	3·5	34·9
VII 10, 20	30′	18° 0′	3·0	·76	12	20′	30′	4·0	35·02
VII 13, 20	74° 10′	17° 30′	5·0	34·53	18	0′	20′	4·5	34·98
VII 14, 10	20′	4′	4·0	·44	24	75° 40′	13° 0′	4·5	35·01
VII 15, 12	30′	30′	0·5	·25	IX 14, 6	13′	14° 0′	5·0	·06
VII 16, 8	40′	18° 20′	0·0	·29	12	74° 30′	16° 0′	5·0	·19
VII 17, 8	75° 10′	19° 12′	0·0	·40	18	0′	14° 40′	6·5	·16
20	25′	20′	— 0·2	·29	IX 15, 6	73° 50′	15° 0′	6·0	·15
VII 18, 18	35′	30′	— 0·5	·19	12	0′	55′	6·0	·15
24	40′	0′	0·0	·29	IX 16, 8	72° 30′	16° 0′	6·0	·04
VII 19, 12	38′	18° 30′	0·0	·48	16	71° 44′	30′	7·0	·01
VII 20, 20	45′	0′	1·0	·34	20	20′	17° 0′	7·5	·02
VII 21, 8	35′	17° 40′	0·5	33·86	IX 17, 8	70° 40′	30′	7·5	·12
VII 23, 8	10′	20′	4·5	34·75	12	0′	0′	7·5	34·99
16	5′	30′	3·5	·35	16	10′	30′	8·0	·24
VII 24, 20	25′	18° 0′	2·0	·00	20	20′	18° 0′	8·5	·28
VII 26, 6	35′	40′	2·0	33·79	IX 18, 6	69° 50′	17° 0′	7·5	33·12
VII 27, 8	76° 30′	16° 35′	1·0	·10	11	35′	18° 0′	7·0	·10
VII 29, 8	40′	20′	2·0	·30					

Thora den Blide, Capt. P. CHR. ISAKSEN, of Tromsø. **1902.**

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	E				N	E		
V 8, 12	71° 10′	26° 40′	2·2	34·75	V 19, 12	73° 20′	34° 15′	0·5	34·25
V 9, 12	53′	32° 4′	1·5	·74	V 21, 12	0′	0′	— 1·0	·875
24	72° 3′	34° 10′	0·5	·77	V 22, 12	25′	33° 20′	— 2·0	·41
V 10, 12	13′	15′	0·5	·79	V 23, 18	0′	20′	— 1·5	·77
V 11, 18	71° 30′	35° 20′	— 1·0	·42	V 24, 12	35′	35° 3′	— 2·0	·68
V 12, 24	70° 50′	36° 30′	— 2·0	·70	V 25, 18	72° 12′	10′	— 1·4	·78
V 13, 12	71° 15′	34° 40′	— 2·0	·43	24	71° 50′	36° 3′	— 1·3	·47
V 15, 12	73° 0′	20′	— 1·5	·32	V 26, 12	30′	10′	— 1·1	·36
V 16, 12	3′	25′	— 1·5	·28	V 27, 12	33′	0′	— 1·3	·46
V 18, 12	72° 50′	4′	— 0·5	·35	V 28, 12	12′	15′	— 1·1	·35

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	E				N	E		
V 29, 12	70° 50′	36° 20′	— 1·0	34·27	VI 16, 18	74° 55′	30° 20′	0·5	34·87
V 30, 12	71° 5′	37° 30′	— 1·1	·18	VI 17, 12	75° 2′	23° 10′	1·0	·79
V 31, 24	70° 50′	40′	— 1·5	·11	VI 18, 12	74° 39′	20° 30′	1·5	35·08
VI 1, 12	71° 5′	38° 10′		·14	VI 19, 12	35′	18° 10′	2·0	34·92
VI 3, 12	45′	37° 40′	— 2·0	·43	VI 20, 12	13′	19° 0′	— 0·5	·73
VI 4, 12	20′	38° 20′	— 1·0	·23	VI 21, 12	45′	21° 10′	0·0	·86
VI 5, 12	17′	39° 0′	— 1·0	·14	VI 22, 12	50′	22° 0′	1·0	·85
VI 6, 12	35′	10′	— 1·0	·41	VI 23, 12	75° 5′	23° 10′	0·5	·78
VI 7, 6	30′	36° 40′	— 0·3	·59	18	74° 40′	15′	1·2	35·01
12	35′	0′	1·0	·61	VI 24, 18	55′	22° 0′	1·3	·09
VI 8, 12	50′	35° 40′	1·0	·81	VI 27, 12	35′	21° 20′	1·5	34·89
VI 9, 4	72° 10′	10′	1·3	·81	VI 29, 24	35′	22° 20′	2·0	·58
VI 11, 12	45′	40′	0·5	·61	VII 6, 12	75° 5′	23° 20′	2·5	·71
VI 12, 12	73° 40′	20′	1·0	·71	24	10′	24° 20′	2·0	·18
18	74° 15′	15′	1·5	35·00	VII 7, 24	7′	25° 30′	0·5	33·66
24	35′	34° 50′	1·0	34·67	VII 11, 12	74° 38′	26° 10′	0·5	32·77
VI 13, 6	50′	10′	1·0	·79	VII 16, 12	45′	22° 5′	— 0·3	33·02
24	75° 10′	30′	— 0·5	·11	VII 21, 12	35′	18° 0′	2·0	34·05
VI 16, 12	74° 40′	32° 10′	0·5	·98					

Vega, Capt. A. MARCUSSEN, of Sandefjord. **1902.**

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	E				N	E		
III 8, 18	58° 20′	5° 42′	1·5	32·00	III 17, 8	70° 59′	0° 48′	2·7	35·25
22	37′	8′	1·5	·00	12	71° 20′	1° 20′	2·0	·18
III 9, 2	50′	4° 30′	2·5	·20	16	32′	56′	2·0	·29
7	59° 8′	1′	4·0	34·51	19	43′	0′	1·5	·18
12	28′	3° 30′	4·7	35·32	22	52′	0° 25′	— 1·5	34·66
18	46′	3′	4·7	·30			W		
23	54′	2° 43′	4·7	·27	III 18, 8	72° 1′	0° 30′	— 2·0	·56
III 10, 6	60° 16′	26′	4·7	·37	14	15′	1° 20′	— 2·0	·73
11	35′	1° 30′	5·0	·48	20	25′	2° 1′	— 2·0	·80
14	46′	20′	5·2	·48	III 19, 6	41′	2° 40′	— 2·0	·87
17	59′	10′	5·7	·37	12	73° 0′	3° 1′	— 2·0	·95
20	61° 12′	25′	5·7	·40	III 20, 12	72° 29′	5° 47′	— 2·0	·95
III 11, 4	24′	50′	5·7	·14	18	18′	7° 17′	— 2·0	·97
12	37′	2° 13′	5·2	·08	IV 11, 20	69° 8′	11° 45′	— 2·0	·91
20	56′	3′	4·7	·10	V 4, 12	74° 12′	4° 29′	— 1·7	·82
III 12, 2	62° 18′	1° 53′	4·7	·075	17	26′	40′	— 1·7	·91
7	38′	45′	5·5	·47	20	40′	53′	— 1·5	·94
12	58′	34′	5·5	·44	24	56′	5° 7′	— 1·2	·95
15	63° 17′	26′	5·0	·25	V 5, 8	75° 8′	20′	— 1·2	·83
18	35′	15′	5·2	·38	12	20′	32′	— 1·5	·68
20	54′	6′	5·2	·29	20	18′	55′	— 1·7	·70
23	64° 12′	0° 55′	5·0	·24	V 6, 4	28′	6° 20′	— 1·7	·55
III 13, 2	31′	44′	4·7	·17	20	37′	25′	— 2·0	·67
5	49′	32′	4·5	·34	V 8, 24	50′	5° 22′	— 1·7	·51
8	65° 8′	20′	4·5	·24	V 9, 12	76° 10′	3° 50′	— 1·7	·80
12	28′	5′	4·0	·17	22	75° 45′	2′	— 1·0	·98
		W			V 10, 8	20′	4° 25′	— 2·0	·58
16	45′	0° 16′	4·0	·13	20	35′	5° 0′	— 2·0	·90
20	66° 2′	37′	4·0	·25	V 13, 24	44′	3° 30′	— 1·7	·87
III 14, 4	19′	50′	3·2	·04	V 19, 24	73° 14′	5° 9′	— 1·7	·785
8	36′	1° 8′	2·2	·07	V 21, 20	72° 53′	6° 10′	— 1·7	·74
12	52′	20′	2·7	·14	V 22, 12	0′	9° 20′	— 1·5	·66
16	67° 13′	6′	3·0	·14	15	71° 47′	50′	— 1·7	·61
20	34′	0° 50′	2·7	·19	18	32′	10° 20′	— 1·7	·47
III 15, 4	56′	42′	3·2	·16	21	20′	50′	— 1·5	·51
12	68° 8′	26′	4·0	·16	24	4′	11° 10′	— 1·7	·36
17	27′	24′	3·0	·13	V 23, 3	70° 50′	40′	— 1·7	·49
21	46′	22′	3·0	·30	6	35′	58′	— 1·7	·58
24	69° 2′	20′	3·0	·23	9	20′	12° 30′	— 1·2	·66
III 16, 4	21′	18′	3·0	·32	12	0′	13° 4′	— 1·2	·57
8	40′	19′	3·0	·19	15	69° 42′	41′	— 1·2	·63
12	70° 1′	14′	3·0	·23	18	24′	14° 18′	— 1·2	·56
18	21′	0′	3·0	·24	21	6′	55′	— 1·2	·34
		E			24	68° 50′	15° 30′	— 1·2	·36
III 17, 2	42′	0° 16′	3·0	·25	V 24, 3	32′	16° 0′	— 1·5	·39

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	W				N	W		
V 24, 6	68° 14′	16° 37′	— 1·7		VII 13, 8	65° 28′	11° 42′	3·2	
9	67° 56′	17° 14′	— 1·7	34·33	12	17′	6′	3·2	
12	40′	18° 0′	— 1·5	·12	16	7′	10° 49′	3·7	
20	30′	32′	— 1·0	33·77	20	64° 56′	22′	4·0	
V 25, 4	24′	19° 1′	— 1·0	·81	VII 14, 4	43′	9° 52′	4·0	
8	19′	45′	— 0·7	·95	12	36′	17′	4·7	
12	15′	21° 26′	— 0·2	34·35	16	18′	8° 58′	5·7	
24	0′	22° 0′	0·2	·37	22	1′	39′	6·0	
V 26, 8	66° 47′	32′	0·7	·57	VII 15, 3	63° 42′	20′	6·7	
V 28, 13			2·0	·66	8	23′	7° 59′	7·2	
V 30, 12	65° 57′	25° 48′	4·0	35·71	12	5′	41′	7·2	
16	66° 1′	26° 9′	4·0		16	62° 53′	11′	6·7	
20	5′	30′	— 0·2		20	41′	6° 38′	5·5	
V 31, 4	10′	51′	— 1·0		23	30′	2′	6·0	
12	15′	27° 14′	— 1·0		VII 16, 2	18′	5° 32′	6·5	
VI 8, 12		28° 15′	0·2		5	61° 53′	5°	7·0	
VI 11, 20	25′	27° 40′			8	39′	4° 30′	7·2	
VI 13, 12	15′	28°			12	28′	3°	7·2	
VII 11, 4	67° 12′	18° 20′	3·0		16	16′	2° 30′	7·7	
12	66° 59′	17° 24′	4·0		20	4′	1′	8·0	
16	45′	16° 18′	4·2		24	60° 52′	1° 30′	8·2	
20	35′	15° 40′	4·0		VII 17, 4	40′	0° 58′	8·5	
24	28′	1′	4·0		8	30′	20′	8·5	
VII 12, 12	23′	14° 35′	4·5				E		
16	12′	1′	4·2		12	23′	0° 50′	9·0	
20	2′	13° 36′	4·0		16		1° 15′	9·2	
24	65° 50′	2′	3·7		20	59° 48′	50′	9·5	
VII 13, 4	38′	12° 30′	3·5		24	37′	2° 15′	9·7	

Aksel, Capt. N. J. NIELSEN, of Sandefjord. **1903.**

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	W				N	W		
VI 25, 8	61° 43′	1° 2′	8·1	35·37	V 9, 12	61° 11′	8° 16′	8·1	
20	62° 1′	16′	·0	·31	16	3′	7° 50′	7·9	35·34
VI 26, 4	18′	31′	6·6	·20	20	5′	20′	·8	·37
VI 27, 8	30′	46′	7·3	·21	V 10, 4	7′	6° 50′	6·7	
VI 28, 12	33′	40′	6·9	·23	8	15′	12′	·4	35·23
VI 29, 10	37′	47′	·7	·29	12	7′	5° 30′	7·5	·30
16	33′	44′	7·2		16	14′	6′	6·8	·24
20	32′	2° 11′	·1	35·28	20	22′	4° 17′	7·4	·36
VI 30, 8	31′	3° 4′	·2	·24	V 11, 4	31′	3° 31′	8·1	
12	32′	24′	·3	·23	8	35′	12′	7·7	35·37
16	31′	56′	·4	·25	12	24′	10′	·6	
20	31′	4° 31′	·0	·26	V 12, 8	21′	2° 50′	6·7	35·34
V 1, 4	31′	5° 37′	5·9	·11	12	20′	45′	·8	
8	32′	6° 2′	6·1	·14	16	23′	33′	7·4	
12	36′	28′	7·4	·16	20	25′	30′	·3	
18	36′	7° 17′	·6	·24	V 13, 8	62° 8′	1° 35′	·2	35·28
20	35′	23′	·6		12	11′	48′	·8	
V 2, 4	29′	40′	·7	35·27	16	14′	2° 0′	·2	
8	27′	8° 20′	·8		20	18′	9′	6·9	35·24
12	10′	40′	·8	35·28	V 14, 4	30′	20′	7·4	
16	8′	10′	6·7	·23	8	36′	25′	·1	35·29
20	5′	7° 50′	7·4	·25	12	43′	30′	·5	
V 3, 12	61° 40′	10′	6·5	·21	16	51′	43′	6·7	35·21
V 4, 8	40′	10′	·5	·24	20	63° 6′	3° 6′	·5	·23
V 5, 8	40′	10′	·4	·18	V 15, 8	29′	18′	5·3	·08
16	50′	30′	7·1		12	39′	34′	4·9	34·95
20	62° 0′	40′	6·8	35·28	16	46′	20′	·3	
V 8, 8	61° 33′	50′	7·9	·30	20	50′	20′	3·8	34·83
12	22′	8° 5′	·9		V 16, 8	44′	18′	·9	·89
16	8′	10′	·9	35·30	12	36′	28′	4·1	
20	3′	20′	·2	·37	16	44′	28′	3·8	
V 9, 4	4′	54′	7·3	·28	20	54′	24′	4·2	35·03
8	6′	34′	·3	·26	V 17, 8	64° 6′	2° 43′	·2	34·97

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	W				N	W		
V 17, 16	64° 16′	2° 20′	4·1	35·14	V 21, 12	65° 47′	8° 3′	1·7	
20	14′	36′	·2		16	66° 2′	48′	·3	
V 18, 8	63° 56′	3° 37′	·6	34·96	20	17′	9° 33′	·2	
12	56′	37′	5·8		24	23′	53′	0·6	
20	58′	40′	·3		V 22, 4	24′	57′	·6	
V 19, 8	64° 19′	50′	4·3	34·95	8	27′	10° 6′	·6	
12	23′	58′	3·6		12	41′	19′	·7	
20	29′	4° 10′	·9	34·86	16	54′	58′	·0	
V 20, 4	36′	27′	·3		20	59′	11° 6′	— 0·6	
8	39′	34′	·5	34·85	V 23, 4	67° 12′	18′	— ·6	
12	41′	57′	·5	·83	8	17′	11′	— ·5	
16	52′	5° 35′	·5	·83	16	19′	10° 46′	— ·6	
20	65° 1′	59′	2·9	·74	20	13′	28′	— ·6	
24	11′	6° 25′	1·9	·78	V 24, 4	12′	33′	— ·5	
V 21, 4	22′	55′	·3	·78	8	17′	45′	— ·3	
8	34′	7° 30′	0·9						
Fortuna, Capt. A. B. Abrahamsen, of Sandefjord. **1903.**									
June 1903.					**July 1903.**				
	N	W				N	W		
VI 1, 15	67° 15′	14° 30′	1·0	34·51	VII 22, 16	62° 55′	7° 0′	9·0	35·31
VI 6, 11	68° 0′	10° 30′	2·0		VII 24, 14	63° 0′	6° 30′	9·0	·47
VI 13, 16	66° 30′	9° 45′	2·5	·81	VII 25, 11	0′	5° 0′	10·0	·19
VI 17, 14	65° 0′	8° 10′	4·5	·88	VII 26, 14	62° 43′	4° 0′	10·0	·21
VI 25, 11	63° 17′	4° 0′	7·0	35·16					
Hvidfisken, Capt. Fr. Svendsen, of Tromsø. **1903.**									
	N	E				N	E		
V 9, 12	70° 1′5	17° 19′	4·6	34·31	VI 3, 12	75° 44′	8° 0′	2·2	35·02
20	12′	5′	4·6	·60	VI 4, 12	76° 4′	10° 8′	2·2	34·96
V 10, 8	33′	16° 39′	4·6	·52	VI 5, 12	12′	7° 54′	2·8	·98
12	47′	17′	5·6	35·01	VI 6, 12	5′	9° 37′	2·3	35·05
20	71° 15′	15° 19′	5·3	·09	VI 7, 12	35′	8° 45′	2·7	·01
V 11, 12	39′	44′	5·4	·06	VI 8, 12	44′	11° 27′	2·7	·02
24	55′	31′	4·9	·08	VI 9, 12	19′	12° 9′	2·4	·08
V 12, 12	72° 11′	16′	4·8	·05	VI 10, 12	14′	12′	3·4	·31
V 13, 12	23′	14° 55′	4·9	·05	VI 11, 12	51′	10° 10′	2·2	34·99
V 14, 12	46′	13° 36′	4·7	·08	VI 12, 12	75° 33′	12° 29′	3·4	35·07
V 15, 12	73° 11′	11° 17′	3·7	·08	24	14′	11° 38′	3·7	·07
V 16, 12	18′	9° 41′	0·8	34·63	VI 13, 12	35′	13′	2·5	·04
V 17, 12	74° 0′	25′	4·0	35·11	VI 14, 8	50′	10° 54′	2·5	·02
20	6′	8° 55′	2·5	·04	VI 15, 20			3·1	·07
V 18, 12	34′	44′	2·0	·20	VI 16, 12	6′	12° 22′	4·5	·08
20	50′	48′	2·3	34·95	24	74° 49′	11° 37′	3·3	·03
V 19, 12	48′	54′	2·4	33·24	VI 17, 12	38′	10° 46′	3·3	34·98
V 20, 12	75° 28′	9° 9′	2·6	34·96	24	28′	17′	3·7	35·13
V 21, 4	43′	7° 8′	1·1	·78	VI 19, 12	75° 4′	28′	2·5	34·77
12	46′	43′	2·1	·91	20	23′	8° 40′	3·8	35·01
V 22, 12	50′	8° 40′	2·7	35·03	VI 20, 12	45′	7° 16′	1·4	34·60
V 23, 12	76° 12′	9° 2′	2·5	·01	VI 21, 12	38′	5° 57′	1·4	·53
V 24, 4	33′	10° 13′	2·9	34·96	VI 22, 12	34′	6° 23′	1·9	·68
20	24′	8° 53′	2·5	·99	VI 24, 12	57′	9° 12′	3·0	·96
V 25, 12	44′	7° 45′	0·5	·95	24	76° 16′	8° 36′	3·3	·97
24	77° 2′	51′	1·1	·83	VI 25, 12	34′	7° 24′	3·8	35·05
V 26, 12	76° 47′	6° 37′	1·7	·90	VI 26, 12	55′	8° 13′	3·4	·00
V 27, 12	51′	9° 7′	2·7	35·00	VI 28, 12	77° 10′	13′	3·4	34·97
24	48′	10° 21′	2·8	34·81	VI 29, 4	32′	7° 57′	3·4	·90
V 28, 12	27′	40′	2·5	35·02	20	13′	8° 22′	3·3	35·06
V 29, 4	13′	40′	3·0	·00	VI 30, 12	76° 54′	37′	3·3	34·96
12	2′	37′	2·1	·02	VII 1, 8	54′	10° 8′	4·1	·99
V 30, 12	75° 51′	8° 43′	2·9	34·96	20	77° 24′	12° 0′	2·9	33·96
V 31, 12	50′	7° 53′	2·4	35·00	VII 2, 4	13′	14° 17′	1·9	34·29
24	30′	45′	2·0	34·91	12	76° 57′	13° 37′	3·2	·39
VI 1, 20	31′	9° 42′	2·7	35·07	VII 3, 12	77° 30′	26′	2·8	·00
VI 2, 12	45′	8° 13′	2·4	·07	VII 4, 8	33′	15° 13′	2·4	32·79
24	37′	6° 44′	2·2	·01	VII 17, 20	33′	12′	2·4	33·75

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	E				N	E		
VII 26, 20	77° 33′	15° 12′	4·7	33·06	IX 2, 16	72° 56′	17° 36′	7·4	34·76
VIII 10, 20	33′	12′	3·7	32·50	20	36′	58′	7·7	·63
VIII 14, 20	33′	12′	0·2	31·42	24	21′	18° 13′	7·8	·60
VIII 23, 20	33′	12′	2·8	32·01	IX 3, 4	8′	25′	8·2	·34
VIII 27, 20	32′	14° 39′	2·2	31·50	8	71° 46′	9′	8·3	·42
VIII 29, 20	40′	18′	2·4	·70	20	28′	17° 40′	8·2	·22
VIII 30, 12	26′	13° 30′	2·0	32·67	IX 4, 20	72° 11′	59′	8·2	·39
20	8′	14° 7′	1·7	·56	IX 5, 8	71° 33′	19° 11′	8·2	·48
VIII 31, 8	76° 55′	40′	1·3	·40	12	29′	32′	8·1	·47
IX 1, 8	16′	13° 58′	3·9	34·42	20	2′	41′	8·0	·33
16	75° 33′	14° 38′	6·1	·96	IX 6, 8	70° 52′	47′	8·0	·26
20	19′	15° 12′	6·4	·95	12	35′	54′	8·0	·20
IX 2, 4	74° 25′	16° 18′	6·9	·87	IX 7, 8	31′	40′	9·1	33·96
8	73° 48′	48′	6·7	·62	IX 8, 8	3′	20° 2′	8·6	·90
12	15′	17° 17′	7·5	·61	20			8·0	·13
Rivalen, Capt. H. Andresen, of Tromsø. **1903.**									
	N	E				N	W		
V 14, 12	69° 45′	18° 30′	4·0	34·29	VII 4, 12	74° 20′	6° 0′	1·0	33·65
24	25′	0′	5·0	·37	VII 7, 8	33′	8° 0′	0·5	·64
V 15, 8	45′	17° 50′	5·0	·42	VII 10, 6	50′	6° 0′	1·0	·75
12	50′	40′	5·2	·74	24	75° 5′	4° 0′	2·0	34·60
20	70° 10′	20′	5·0	·48	VII 12, 6	20′	2° 0′	1·8	·14
V 16, 4	25′	16° 40′	5·0	35·07	12	53′	30′	1·8	·45
8	40′	0′	5·2				E		
12	71° 0′	12° 0′	5·2		VII 14, 24	76° 50′	1° 40′	0·0	33·48
16	15′	10° 30′	4·8	35·13	VII 15, 19	77° 10′	3° 0′	1·0	·50
24	30′	8° 10′	4·8	·30	VII 17, 24	30′	30′	1·0	·68
V 17, 8	45′	6° 5′	4·0	·17	VII 18, 12	56′	4° 0′	2·2	34·53
16	72° 30′	0′	3·5	·04	VII 20, 12	78° 26′	2° 0′	3·0	·33
24	55′	5° 50′	3·0	·14	24	30′	5° 0′	4·0	·74
V 18, 12	73° 25′	4′	−0·5	34·47	VII 21, 8	79° 0′	10° 0′	3·2	·17
24	45′	6° 10′	−1·0	·35	VII 23, 20	52′	50′	2·0	·41
V 19, 18	74° 0′	0′	−1·0	·46	VII 25, 12	56′	12° 0′	2·0	33·73
24	10′	4° 40′	−1·5	·39	VII 30, 12	58′	30′	2·0	32·88
V 20, 7	20′	2° 0′	−1·8	·74	VIII 1, 12	52′	13° 50′	2·0	34·24
12	35′	0° 50′	−2·0	·81	VIII 6, 20	40′	20′	2·5	·22
		W			VIII 7, 24	80° 5′	12° 10′	1·5	33·63
18	74° 55′	2° 0′	−2·0	34·72	VIII 8, 20	29′	13° 40′	1·5	·59
23	55′	4° 0′	−2·2	·83	VIII 13, 12	79° 48′	14° 20′	2·0	·71
V 21, 6	75° 10′	5° 30′	−2·2	·73	VIII 16, 6	80° 18′	18° 0′	−1·0	·54
V 22, 24	15′	6° 0′	−1·5	·28	24	10′	17° 40′	1·0	·62
V 24, 20	0′	7° 20′	−2·0	33·80	VIII 19, 24	14′	18° 20′	−0·5	32·45
V 26, 20	10′	6° 30′	−2·0	34·19	VIII 23, 24	32′	20° 0′	0·0	33·22
V 27, 20	20′	3° 20′	−2·0	33·68	VIII 31, 8	40′	30′	0·0	32·76
V 29, 12	76° 4′	3° 0′	−1·8	·53	24	30′	22° 10′	−1·0	·89
V 30, 8	15′	1° 20′	−1·8	·75	IX 5, 12	79° 50′	15° 30′	2·5	34·29
V 31, 6	0′	0° 0′	−1·0	34·74	IX 10, 12	18′	16° 10′	1·0	33·87
		E			IX 12, 18	54′	12° 20′	2·5	·69
VI 1, 8	76° 10′	1° 0′	−1·5	34·78	IX 15, 20	52′	10° 50′	2·5	·59
VI 2, 18	20′	0° 0′	−1·2		IX 17, 6	40′	11° 40′	1·8	·12
24	18′	1° 0′	−1·2	34·45	IX 20, 6	33′	10° 20′	1·5	·10
VI 3, 12	33′	30′	−1·0	·37	12	0′	9° 20′	2·0	·95
VI 4, 12	25′	2° 20′	−0·8	·73	18	78° 35′	0′	2·5	34·67
		W			24	5′	30′	2·0	·53
VI 5, 24	76° 30′	1° 30′	−1·0	34·78	IX 21, 6	77° 35′	13° 20′	1·0	33·46
VI 8, 12	20′	2° 0′	−1·0		18	0′	10′	1·0	·40
VI 9, 24	10′	30′	−1·0	33·08	IX 22, 12	76° 20′	15° 10′	1·0	·54
VI 14, 20	75° 50′	3° 0′	−1·0	34·65	18	75° 55′	0′	1·5	34·55
VI 17, 8	30′	1° 0′	−1·0	·84	24	30′	0′	2·0	·56
VI 19, 20	10′	3° 54′	−1·0	·79	IX 23, 3	10′	10′	4·0	35·05
VI 20, 16	0′	4° 0′	−1·0	·74	6	74° 50′	20′	4·5	·03
VI 21, 20	74° 50′	20′	−0·8	·78	9	30′	25′	5·0	·06
VI 23, 12	25′	6° 0′	−0·5	·40	12	15′	40′	5·5	34·97
VI 25, 20	20′	9° 8′	0·0	·40	16	0′	16° 0′	5·8	·97
VI 28, 12	25′	8° 6′	0·5	·38	20	73° 50′	0′	6·0	·95
VII 1, 8	30′	4° 30′	1·0	·26	24	30′	50′	6·2	·94

Time.	Lat.	Long.	t° C.	S ‰	Time.	Lat.	Long.	t° C.	S ‰
	N	E				N	E		
IX 24, 4	73° 15′	17° 0′	6·5	34·96	IX 26, 12	69° 40′	17° 0′	9·0	33·91
12	72° 55′	10′	7·0	·98	16	20′	16° 40′	8 5	·89
18	35′	18° 0′	8 0	·97	IX 27, 6			8·5	34·20
24	16′	17° 50′	8·0	35·03	16			8·0	·05
IX 25, 6	71° 55′	30′	7·5	·01	24			6·5	
12	30′	18° 40′	8·0	34·83	IX 28, 12			6·0	
18	10′	0′	8·0	35·04	IX 29, 6			6·2	32·66
24	70° 55′	17° 40′	8·2	·05	9			6·2	·56
IX 26, 4	36′	30′	9·0	33·58	IX 19, 10			5·0	33·41

Thora den Blide, Capt. P. Chr. Isaksen, of Tromsø. **1903.**

Time.	Lat.	Long.	t° C.	S ‰	Time.	Lat.	Long.	t° C.	S ‰
	N	E				N	E		
IV 19, 18	70° 25′	21° 26′	3·0	34·49	VI 6, 18	75° 20′	33° 20′	— 1·5	·45
IV 20, 6	31′	22° 56′	3 0	·65	VI 7, 6	30′	0′	— 1·5	·49
IV 24, 12	51′	23° 47′	3·0	·57	18	30′	32°	— 1·5	·54
IV 25, 16			3·0	·71	VI 9, 12	45′	30°	— 1·5	·10
24	71° 10′	27°	3·5	·78	24	45′	29°	— 1·5	·40
IV 26, 6	0′	29°	3·0	·77	VI 11, 12	35′	28° 30′	— 1·5	·52
16	70° 50′	30° 10′	3·0	·82	VI 13, 12	76° 0′	25°	— 0·5	·17
VI 27, 8	10′	31° 50′	3·0	·82	24	15′	25°	0·5	·50
16	11′	33° 10′	2·5		VI 15, 6	75° 50′	28°	0·0	·34
20	69° 55′	35° 8′	2·5	·80	VI 16, 12	76° 30′	29°	1·0	·80
IV 28, 8	70° 3′	12′	2·0	·84	VI 17, 12	0′	27°	1·0	·89
18	20′	30′	1·5	·84	VI 18, 12	75° 30′	25°	0·5	33·87
IV 29, 6	30′	37°	0·5	·89	VI 19, 6	25′	24°	0·5	34·21
12	49′	39° 28′	— 1·0	·69	VI 20, 6	10′	23° 50′	1·0	·14
18	50′	41°	— 1·0	·69	VI 21, 6	35′	30′	— 1·0	33·62
IV 30, 4	30′	42° 10′	— 0·5	·44	12	20′	5′	— 1·0	·75
16	10′	41° 50′		·55	24	15′	21° 30′	1·0	34·42
V 1, 16	10′	30′	— 1·5	·54	VI 23, 12	15′	20°	2·0	·44
V 2, 12	0′	40° 30′	— 2·0	·71	VI 24, 12	20′	19° 10′	0·5	·23
V 4, 6	69° 40′	41° 10′	— 2·0	·33	VI 25, 12	35′	19° 0′	— 0·5	
V 5, 12	25′	50′	— 1·5	·50	VI 26, 12	74° 50′	20°	— 1.0	
V 6, 24	40′	42° 0′	— 1·5	·49	VI 27, 12	40′	22°	— 1·0	34·18
V 7, 12	70° 10′	10′	— 1·5	·39	VI 29, 6	50′	23°	1·0	·08
V 10, 12	0′	41° 40′	— 2·0	·38	VI 30, 6	50′	23°	1·0	33·77
V 11, 18	25′	0′	— 1·5	33·47	VII 2, 12	40′	22° 30′	2 0	34·26
V 12, 12	58′	43°	— 2·0	34·76	VII 5, 12	75° 0′	30′	1·5	33·46
V 13, 12	71° 40′	42°	— 0 5	·76	VII 6, 12	74° 45′	10′	1·5	·50
18	72° 0′	42°	0·0	·78	VII 7, 12	50′	21° 20′	1·0	32·74
V 14, 12	20′	41° 30′	0 0	·58	VII 9, 12	75° 0′	22° 0′	1·0	·84
V 15, 12	12′	40° 30′	— 1·0	·45	VII 12, 12	30′	30′	1·0	
V 17, 12	15′	39° 30′	— 1·0	·49	24	36′	23° 30′	1·0	34·38
V 20, 12	20′	40°	— 1·0	·36	VII 15, 12	30′	0′	1·0	33·68
V 22. 6	30′	39°	— 0·5	·69	VII 17, 24	15′	22° 10′	1·5	·19
V 23, 12	73° 20′	38° 40′	0·0	·84	VII 19, 12	74° 40′	0′	2 5	34·56
V 26, 18	45′	39° 0′	— 1·0	·17	18	15′	21° 30′	4·0	35·04
V 27, 12	72° 55′	30′	— 1·0	·19	24	73° 35′	30′	5·0	·04
V 28, 24	35′	40° 30′	— 1·0	·63	VII 20, 12	0′	0′	5·0	·06
V 31, 12	40′	38°	— 0·5	·75	24	72° 20′	0′	5·5	34·97
VI 3, 12	73° 5′	39°	— 1·5	·22	VII 21, 12	0′	22° 0′	6·0	35·07
VI 4, 12	30′	38° 30′	— 1·5	·34	24	71° 40′	23° 0′	6.5	34·88
24	55′	0′	— 1·5	·60	VII 22, 6	15′	22° 30′	7.0	33·51
VI 5, 18	74° 25′	37°	— 1·5	·64	12	70° 40′	23° 0′	7·0	·52
VI 6, 6	50′	35° 40′	— 1·5	·78					

Aksel, Capt. N. J. Nielsen, of Sandefjord. **1903.**

Time.	Lat.	Long.	t° C.	S ‰	Time.	Lat.	Long.	t° C.	S ‰
	N	W				N	W		
IV 17, 20	61° 20′	0° 30′	7·5	35·32	IV 23, 8	62° 40′	2° 2′	7·5	35·21
IV 18, 8	0′	1° 39′	7·7	·19	12	39′	35′	7·5	·15
16	19′	2° 0′	7·5	35·22	20	43′	3° 9′	7·5	·16
IV 19, 8	24′	50′	7·5	35·24	IV 24, 8	63° 0′	24′	5·5	34·98
20	31′	40′	7·5	35·24	20	5′	37′	5·4	·96
IV 20, 20	44′	2° 0′	7·0	35·20	IV 25, 8	62° 37′	57′	6·5	35·24
IV 21, 8	63° 4′	40′	6·5	·11	20	28′	40′	7·0	·11
20	62° 46′	8′	7·5	·20	IV 26, 8	30′	1° 48′	6·4	·11
IV 22. 8	45′	1° 44′	7·2	·16	20	38′	34′	7·0	·20

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	W				N	W		
IV 27, 8	62° 40′	1° 49′	6·5	35·15	VI 1, 20	67° 1′	11° 26′	1·9	34·61
20	39′	2° 41′	7·0	·21	VI 2, 12	10′	12° 27′	1·4	·62
IV 28, 8	27′	1° 54′	8·2	·24	VI 3, 8	17′	12′	2·0	·64
20	31′	2° 14′	7·5	·25	20	4′	44′	2·5	·66
IV 29, 20	30′	3° 47′	5·5	34·96	VI 4, 8	5′	6′	2·5	·68
IV 30, 8	58′	5° 3′	3·2	·70	20	2′	11° 57′	2·5	·65
12	63° 15′	29′	5·5	35·15	VI 5, 12	7′	12° 14′	2·5	·63
16	33′	56′	4·5	34·91	VI 6, 8	17′	5′	2·5	·65
20	51′	6° 25′	3·0	·74	VI 7, 8	11′	11° 55′	3·0	·60
V 1, 8	45′	41′	2·5	·72	VI 8, 8	0′	12° 3′	3·0	·69
V 2, 8	64° 11′	55′	2·3	·65	20	2′	11° 28′	2·5	·64
20	35′	7° 21′	2·0	·87	VI 9, 8	10′	39′	2·2	·63
V 3. 8	53′	8° 23′	1·5	·66	20	22′	12° 5′	3·0	·64
16	57′	9° 2′	1·5	·62	VI 10, 8	21′	49′	2·8	·64
V 4, 8	65° 0′	6′	1·2	·68	20	0′	0′	4·3	·67
20	21′	28′	1·2	·60	VI 11, 20	1′	53′	4·0	·66
V 5, 8	66° 0′	10° 11′	1·2	·67	VI 13, 8	7′	11° 34′	3·5	·63
16	22′	36′	1·0	·68	20	24′	10° 30′	3·1	·64
V 6, 8	24′	11° 15′	0·2	·60	VI 14, 8	1′	36′	3·7	·61
V 7, 8	22′	20′	0·5	·69	20	66° 52′	47′	4·0	·61
20	27′	30′	0·5	·64	VI 15, 8	51′	18′	3·6	·64
V 8, 8	28′	32′	1·0	·63	20	38′	9° 16′	4·5	·64
20	34′	42′	0·6	·62	VI 16, 8	25′	8° 19′	4·5	·63
V 9, 8	37′	31′	1·0	·67	20	8′	7° 9′	6·2	·78
20	39′	30′	1·0	·64	VI 17, 8	9′	6° 22′	6·5	·73
V 10, 20	42′	11° 6′	0·5	·60	20	20′	5° 55′	6·5	·88
V 11, 12	58′	12° 5′	0·0	·63	VI 18, 8	3′	6° 9′	6·5	·88
V 12, 20	67° 28′	48′	— 0·5	·62	20	65° 40′	16′	6·3	·82
V 13, 8	33′	39′	0·0	·73	VI 19, 8	42′	5° 26′	6·0	·82
20	24′	35′	0·0	·63	20	23′	6° 8′	5·5	·82
V 14, 8	27′	50′	— 0·2	·66	VI 20, 20	13′	19′	6·0	·68
20	26′	16′	0·0	·59	VI 21, 8	10′	7° 18′	5·5	·61
V 15, 8	19′	11° 23′	0·0	·78	20	0′	6° 55′	5·5	·60
16	15′	10° 56′	0·1	·66	VI 22, 8	64° 43′	7° 8′	6·3	·73
V 16, 8	0′	12° 30′	1·2	·68	12	28′	6° 58′	6·5	·70
20	66° 56′	13° 4′	0·0	·65	16	10′	39′	7·2	·81
V 17, 8	54′	12° 54′	1·0	·69	20	63° 54′	22′	7·4	·81
20	32′	35′	1·6	·69	VI 23, 8	64° 11′	10′	7·0	·76
V 18, 8	10′	16′	1·5	·78	16	63° 42′	4′	8·0	·79
20	7′	11° 40′	0·6	·68	20	30′	5′	8·0	35·08
V 19, 8	13′	10° 58′	0·8	·65	VI 24, 16	18′	12′	8·7	·03
V 20, 8	19′	11° 33′	0·5	·67	VI 25, 8	5′	5° 44′	9·1	·04
20	38′	30′	0·0	·68	20	0′	40′	8·6	34·95
V 21, 8	59′	47′	0·5	·60	VI 26, 8	1′	4° 45′	9·5	35·18
20	67° 11′	50′	0·2	·61	20	4′	3° 54′	9·0	·09
V 22. 8	24′	39′	0·5	·63	VI 27, 8	3′	2° 17′	9·5	·19
20	27′	12° 9′	1·4	·60	12	62° 34′	3′	10·0	·25
V 23, 8	15′	32′	0·5	·62	20	36′	33′	9·5	·21
16	66° 59′	35′	1·0	·68	VI 28, 8	30′	3° 21′	10·1	·18
V 24, 8	67° 25′	11° 45′	0·3	·63	20	49′	4° 18′	10·5	·21
20	42′	8′	1·0	·42	VI 29, 8	63° 5′	5° 48′	9·5	·10
V 25, 8	51′	10° 40′	1·0	·68	20	7′	7° 15′	9·6	·20
16	36′	56′	0·7	·63	VI 30, 8	62° 58′	49′	9·5	·14
V 26, 8	43′	58′	1·0	·65	20	51′	8° 4′	10·3	·19
20	42′	43′	1·0	·66	VII 1, 8	54′	2′	9·0	·23
V 27, 8	32′	23′	1·1	·57	VII 2, 8	63° 0′	7° 43′	9·4	·01
20	36′	5′	1·5	·63	20	62° 57′	15′	10·0	·06
V 28, 8	38′	15′	2·0	·58	VII 3, 20	63° 10′	6° 20′	10·5	·07
20	24′	3′	1·7	·60	VII 4, 8	9′	7° 10′	10·9	·16
V 29, 8	31′	9° 10′	1·5	·60	20	8′	18′	10·8	·21
12	29′	10° 4′	1·5	·60	VII 5, 8	7′	41′	10·5	·20
20	16′	29′	1·7	·55	20	10′	7° 56′	10·5	·19
V 30, 8	16′	59′	1·5	·53	VII 6, 8	9′	10′	10·5	10
V 31, 8	5′	11° 11′	1·9	·62	20	4′	6° 42′	9·5	34·93
20	9′	5′	2·2	·59	VII 7, 8	62° 59′	40′	9·4	35·00
VI 1, 8	66° 58′	10° 46′	2·5	·60	20	46′	0′	9·0	34·88

Time.	Lat.	Long.	$t°$ C.	S ‰.	Time.	Lat.	Long.	$t°$ C.	S ‰.
	N	W				N	W		
VII 8, 8	63° 3′	5° 54′	9·7	35·11	VII 14, 8	10′	1° 51′	10·8	·14
20	0′	6° 0′	9·3	·01	20	6′	2° 27′	10·8	·06
VII 9, 8	62° 50′	5° 50′	9·3	·01	VII 15, 8	9′	4° 25′	10·6	34·96
VII 10, 8	57′	40′	10·7	·07	VII 15, 12	9′	5° 9′	11·0	35·02
VII 11, 8	63° 6′	6° 31′	11·3	·49	16	9′	53′	10·6	34·99
20	9′	7° 0′	10·5	·04	20	5′	6° 32′	11·1	35·13
VII 12, 8	6′	6° 2′	10·0	·03	VII 16, 8	0′	55′	11·0	·07
20	6′	5° 1′	10·5	·04	20	62° 47′	7° 46′	10·0	·01
VII 13, 8	7′	4° 20′	10·5	·01	VII 17, 8	55′	42′	10·5	·18
20	10′	3° 2′	10·5	·01	20	63° 2′	45′	10·0	·02
Rivalen, Capt. H. ANDRESEN, of Tromsø. **1904.**									
	N	E				N	W		
V 14, 23	70° 0′	18° 30′	4·0	33·79	VII 6, 8	72° 28′	10° 0′	0·8	32·36
V 15, 8	20′	0′	5·0	34·05	VII 7, 19	44′	9° 0′	2·0	33·21
14	35′	17° 10′	5·5	·83	VII 8, 12	73° 5′	10° 30′	0·0	32·48
20	40′	16° 15′	5·5	·64	19	15′	9° 40′	2·0	33·22
24	50′	0′	5.0	·31	VII 9, 16	30′	8° 0′	3·5	·34
V 16, 6	71° 5′	14° 10′	5·0	·29	VII 10, 10	50′	7° 10′	0·0	32·30
12	20′	13° 0′	5·0	33·21	16	74° 5′	6° 30′	3·5	33·08
18	35′	12° 50′	5·5	·24	24	30′	0′	— 0·5	32·16
V 17, 18	40	0′	5·5	34·83	VII 11, 6	55′	4° 30′	2·0	·71
24	72° 0′	11° 10′	5·0	·83	12	75° 20′	2° 50′	3·5	33·93
V 18. 4	15′	10° 0′	5·0	35·17	18	50′	3° 0′	2·5	34·73
8	40′	9° 10′	5·0	·11	24	76° 10′	10′	2·5	·80
12	50′	8° 20′	5·0	·07	VII 12, 6	20′	15′	2·5	·70
18	73° 10′	7° 10′	4·0	·08	12	40′	20′	3·2	·55
24	25′	6° 40′	4·0	·13	18	77° 0′	30′	3·5	·38
V 19, 4	30′	5° 0′	3·5	·12	VII 13, 10	20′	4° 0′	4·5	·70
8	45′	3° 20′	2·5	·07	24	40′	3° 30′	4·0	·83
12	55′	2° 0′	2·5	·075			E		
18	74° 8′	0° 5′	3·0	·075	VII 14, 6	78° 35′	0° 16′	4·0	·79
		W			18	40′	4° 30′	4·5	·80
24	74° 20′	1° 10′	0·5	34·965	VII 15, 12	79° 10′	9° 30′	5·5	·83
V 20, 6	30′	2° 30′	— 1·5	·95	VII 16, 18	44′	10° 50′	5·5	33·83
12	40′	40′	— 1·5	·85	VII 19, 18	80° 20′	15° 0′	4·0	34·38
18	55′	3° 0′	— 2·0	·88	VII 20, 8	81° 3′	20° 0′	3·5	.28
24	75° 5′	30′	— 2·0	·89	VII 22, 16			3·0	32·04
V 21, 6	10′	4° 35′	— 2·0	·785	VII 28, 18	81° 0′	21° 0′	1·5	·48
20	15′	5° 10′	— 2·0	·79	VIII 21, 8	80° 15′	20° 10′	2·0	·78
V 23, 8	74° 20′	4° 0′	— 1·5	·80	VIII 22, 18	14′	22° 50′	0·5	
V 25, 12	40′	1° 0′	— 1·2	·79	VIII 26, 20	30′	26° 30′	— 1·0	32·00
		E			IX 4, 12	79° 50′	10° 45′	4·0	·81
V 27, 12	75° 0′	1° 50′	— 1·2	34·81	18	20′	8° 30′	4·0	34·51
		W			IX 5, 12	0′	40′	4·0	33·86
V 28, 22	10′	3° 30′	— 1·6	34·80	18	78° 40′	10° 0′	3·5	·86
V 29, 12	25′	4° 10′	— 1·2	·77	24	25′	5′	4·0	34·66
V 31, 8	40′	2° 30′	— 1·5	·80	IX 6, 4	0′	10′	4·5	·95
VI 2, 6	76° 5′	2° 0′	— 1·5	·70	8	77° 35′	0′	5·5	·91
VI 3, 6	15′	1° 0′	— 1·5	·785	12	5′	11° 10′	5·5	·91
		E			20	76° 40′	12° 0′	5·5	·96
VI 4, 7	76° 25′	1° 0′	— 1·0	33·04	IX 7, 4	15′	0′	5·5	·98
VI 5, 22	40′	3 0′	— 1·0	·01	12	75° 52′	11° 20′	6·0	·96
		W			20	35′	10° 50′	6·0	·96
VI 8, 22	76° 35′	4° 20′	— 1·0	34·28	IX 8, 12	75° 50′	14° 30′	6·5	34·98
VI 10, 12	20′	3° 30′	— 1·0	33·01	20	40′	16° 0′	6·5	·96
VI 11, 22	10′	2° 40′	— 0·5		IX 9, 12	20′	14° 10′	6·5	·96
VI 14, 11	75° 5′	50′	— 0·5	34·54	20	5′	0′	7·0	·96
22	74° 30′	1° 15′	— 0·5	·72	24	74° 50′	10′	7·0	35·00
VI 16, 8	15′	2° 0′	— 0·5	·23	IX 10, 4	35′	20′	6·5	·04
VI 17, 22	3′	3° 40′	0·0	·225	8	24′	30′	6·5	·01
VI 21, 10	73° 40′	4° 30′	— 0·2	·045	12	20′	0′	7·0	·02
VI 25, 12	33′	3° 20′	— 0·5	33·58	16	4′	10′	7·0	34·97
VI 29, 23	20′	5° 10′	1·0	·955	20	73° 48′	15′	7·5	·82
VII 1, 12	72° 49′	6° 40′	2·5	·66	IX 11, 4	25′	30′	7·5	·69
24	30′	8° 20′	1·0	·36	12	10′	15° 0′	8·0	
VII 2, 12	15′	2° 0′	0·8	32·67	18	72° 55′	10′	8·0	·35

Time.	Lat.	Long.	t° C.	S ‰.	Time.	Lat.	Long.	t° C.	S ‰.
	N	E				N	E		
IX 11, 24	72° 38′	15° 25′	8·5	34·37	IX 13, 24	70° 5′	17° 0′	9·0	33·70
IX 12, 6	20′	40′	8·5	·37	IX 14, 6	69° 50′	30′	9·0	·78
12	71° 50′	30′	8·5	·86	12	55′	18° 0′	9·0	·33
18	25′	35′	8·5	·86	16			8·5	·36
IX 13, 4	0′	16° 0′	8·5	·42	20			8·5	·15
12	70° 35′	30′	9·0	·39	IX 15, 8			7·5	·50
18	20′	40′	9·0	33·69	12			7·5	32·71

Hvidfisken, Capt. Ingv. Svendsen, of Tromsø. **1904.**

	N	E				N	E		
IV 30, 24	69° 52′	17° 19′	4·8	34·05	V 24, 12	75° 12′	9° 33′	3·2	35·11
V 1, 12	70° 28′	0′	4·4	·86	24	40′	8° 46′	3·5	·06
20	50′	16° 54′	5·6	·99	V 26, 12	76° 8′	6° 58′	3·0	·07
V 2, 12	46′	32′	5·5	·89	VI 2, 12	19′	8° 44′	2·9	·11
20	71° 24′	15° 48′	4·9		VI 3, 12	4′	10° 41′	3·8	·07
V 3, 4	51′	10′	5·2		VI 5, 12	75° 52′	7° 31′	3·4	·06
20	72° 2′	11° 22′	5·0	35·07	VI 7, 12	76° 36′	8° 7′	2·9	·06
V 4, 4	71° 57′	10° 6′	4·6	·08	VI 9, 4	77° 2′	6° 37′	3·0	·06
12	55′	10′	3·6	·07	VI 10, 8	76° 56′	8° 7′	3·1	·00
V 5, 24	30′	5° 23′	4·6		VI 12, 16	22′	9° 12′	4·6	·08
V 6, 12	54′	27′	3·9	35·07	VI 14, 24	75° 29′	9° 0′	4·2	·07
V 7, 12	72° 50′	6° 10′	3·7	·07	VI 17, 12	76° 51′	5° 35′	1·1	34·89
20	73° 3′	21′	3·0	·08	VI 26, 12	77° 58′	6° 17′	4·8	35·07
V 8, 4	16′	8° 1′	4·1	·11	VI 28, 4	78° 9′	7° 0′	4·6	·02
24	58′	50′	2·5	·08	VI 30, 12	77° 41′	9° 43′	4·8	·07
V 9, 12	74° 10′	9° 44′	2·6	·07	24	56′	12° 10′	4·6	34·94
24	6′	10° 58′	3·5	·06	VII 10, 8			2·9	33·15
V 10, 12	9′	11° 59′	4·6	·11	VIII 13, 20	77° 33′	12° 48′	4·7	34·17
V 12, 12	73° 42′	28′	4·7	·08	VIII 14, 24	76° 47′	11° 21′	6·9	·97
V 13, 12	31′	13° 31′	4·9	·07	VIII 15, 8	20′	13′	6·3	35·04
V 15, 12	74° 8′	10° 42′	3·1	·10	20	75° 49′	10′	6·1	·04
24	14′	9° 29′	2·9	·07	VIII 16, 4	22′	50′	6·3	·04
V 16, 12	17′	8° 17′	2·2	·01	12	74° 29′	12° 17′	6·9	·11
V 19, 12	72° 41′	9° 33′	3·5	·07	20			7·8	34·96
V 20, 12	25′	10° 39′	4·5	·12	VIII 17, 12	73° 21′	13° 17′	8·4	·96
V 21, 12	28′	11° 55′	4·8	·07	20	1′	46′	9·2	·87
V 22, 12	57′	13° 19′	4·8	·06	VIII 19, 12	72° 15′	15° 25′	9·4	·47
24	73° 26′	21′	4·3	·02	16	71° 57′	16° 6′	9·5	·57
V 23, 12	74° 24′	11° 49′	4·7	·04	VIII 20, 4	27′	40′	9·8	33·95
24	46′	10° 33′	2·9	·03	20	69° 47′	17° 42′	10·9	·24

Supplement to Tables

Supplementary Table 1.

Surface-Observations, July—September, 1900.

This table was printed for the Memoir originally planned by Nansen on the Cruise of 1900 (mentioned in the Preface).

Supplementary Table 2.

Observations at the Stations, June—July, 1902.

Explanation of Table 1,

showing the Horizontal Distribution of **Temperature, Salinity** and **Density** on the **Surface** of the **Norwegian Sea,** July—Sept., 1900.

1st Column.	Number of the Stations, where series of deep-sea temperatures and water samples were taken.
2nd Column.	Date and Hour of observation.
3rd Column.	North Latitude.
4th Column.	Longitude East (E) or West (W) of Greenwich.
5th Column.	Temperature of Sea Surface, corrected for instrumental errors.
6th Column.	Permillage of Chlorine (Halogen) determined by Titration. An *asterisk* after the figure indicates that two titrations have been made.
7th Column.	Salinity ($^0/_{00}$), derived by M. Knudsen's Tables from permillage of chlorine.
8th Column.	Specific Gravity ($S\frac{0}{4}$) of Water Samples, derived by M. Knudsen's Tables from permillage of chlorine. Decimals from only the second to the fifth place are recorded, 26.73 = 1·02673.
9th Column.	Density ($S\ \frac{t}{4}$) of Surface-Water. 02.79 = 1·00279.

Table 1.

The Temperature, Salinity, and Density of the Sea Surface,

July—September, 1900.

1	2			3	4		5	6	7	8	9
Station	1900 Date and Hour			North Latitude	Longitude		Corr. Temp. of Sea Surf.	Cl. ‰	Salinity ‰	$S\frac{o}{4}$	$S\frac{t}{4}$
	July						°C.				
2	18,	1.30	p.m.	Geiranger Fjord			12·85	1·90	3·46	02.72	02.79
4	19,	4	„	Stor Fjord			10·5	18·415*	33·27	26.73	25.54
5	21,			62° 29′	5° 29′	E	11·1	18·58	33·57	26.97	25.66
6 a	23,	8.30	a.m.	63 2	2 50	„	12·0	18·995	34·32	27.58	26.08
6 b		9.30	„	63 4	2 48	„	11·66	19·23	34·74	27.92	26.48
7		0.30	p.m.	63 6	2 46	„	11·67	19·275	34·82	27.99	26.54
		1.45	„	63 6	2 46	„	11·9				
		11	„	63 10	2 20	„	12·0	19·32	34·90	28.05	26.53
		Midn.		63 14	2 0	„	12·0	19·37	34·99	28.12	26.60
	24,	1	a.m.	63 18	1 39	„	11·8	19·325	34·91	28.06	26.58
		2	„	63 22	1 18	„	11·5	19·35	34·96	28.09	26.67
		3	„	63 26	0 57	„	11·15	19·48	35·19	28.28	26.93
		4	„	63 30	0 36	„	11·4	19·495	35·22	28.31	26.90
		5	„	63 34	0 15	„	11·5	19·51	35·25	28.32	26.89
		6	„	63 38	0 6	W	10·9				
		7	„	63 42	0 27	„	11·1	19·545	35·31	28.38	27.02
		8	„	63 46	0 50	„	11·15	19·53	35·28	28.35	26.99
		9	„	63 51	1 14	„	11·15	19·515	35·26	28.34	26.98
8		10	„	63 51	1 14	„	11·12	19·515	35·26	28.34	26.98
		6.15	p.m.	63 51	1 19	„		19·525	35·27	28.35	27.00
	25,	1	a.m.	63 52	1 23	„	11·0	19·535	35·29	28.36	27.02
		2	„	63 52	1 41	„	10·8	19·545	35·31	28.38	27.08
		4	„	63 52	2 19	„	10·3	19·50	35·23	28.31	27.10
		5	„	63 52	2 35	„	10·2	19·50	35·23	28.31	27.11
		6	„	63 52	2 53	„	10·2	19·475	35·18	28.28	27.08
		7	„	63 52	3 11	„	10·1	19·475	35·18	28.28	27.10
		8	„	65 52	3 29	„	10·3	19·52	35·26	28.34	27.13
		9	„	63 53	3 47	„	10·3	19·50	35·23	28.31	27.10
		11	„	63 53	4 23	„	9·7	19·44	35·12	28.22	27.11
		Noon		63 53	4 41	„	9·7	19·395	35·04	28.16	27.05
		2	p.m.	93 53	5 17	„	9·5	19·41	35·07	28.18	27.10
		3	„	63 53	5 35	„	9·8	19·44	35·12	28.22	27.09
		4	„	63 53	5 52	„	9·4	19·38*	35·01	28.14	27.08
		8	„	63 53	6 15	„	9·1	19·46	35·16	28.25	27.24
9 {		10	„	63 53	6 22	„	9·2	19·45	35·14	28.24	27.21
		11	„	63 53	6 22	„	9·1	19·435*	35·11	28.22	27.21
		Midn.		63 53	6 23	„	9·0	19·435	35·11	28.22	27.22
	26,	1	a.m.	63 53	6 23	„	9·0	19·435	35·11	28·22	27.22
		4	„	63 52	6 25	„	8·8				
		7	„	63 51	6 27	„	8·75	19·435	35·11	28.22	27.26
		2	p.m.	63 48	6 34	„	9·8	19·42	35·08	28.19	27.06
		9	„	63 49	6 47	„	9·8	19·405	35·06	28.17	27.05
	27,	Noon		63 50	7 15	„	9·4	19·335	34·93	28.07	27.01
		3.30	p.m.	63 53	7 24	„	9·2	19·38	35·01	28.14	27.12
		6	„	64 4	8 4	„	8·7	19·37	34·99	28.12	27.18
		8	„	64 21	8 37	„	9·3	19·43	35·10	28.21	27.17
		9	„	64 28	8 54	„	9·3	19·44	35·12	28.22	27.18

1	2	3	4	5	6	7	8	9
Station	1900 Date and Hour	North Latitude	Longitude	Corr. Temp. of Sea Surf.	Cl. ‰	Salinity ‰	S $\frac{0}{4}$	S $\frac{t}{4}$
	July			⁰C.				
	27, 10 p.m.	64° 34′	9° 10′ W	9·3	19·41	35·07	28.18	27.14
	11 „	64 41	9 27 „	9·3	19·415	35·08	28.19	27.15
	Midn.	64 47	9 43 „	9·9	19·435	35·11	28.22	27.08
	28, 3 a.m.	64 53	10 0 „	9·4				
10	4 „	64 53	10 0 „	9·4				
	6.25 „	64 53	10 0 „	9·3	19·40	35·05	28.16	27.00
	1 p.m.	64 53	10 2 „	10·0				
	5 „	64 53	10 2 „		19·395	35·04	28.16	27.00
	7 „	65 1	10 29 „	10·0	19·375	35·00	28.13	26.97
	9 „	65 15	11 13 „	8·9				
	9.15 „	65 17	11 18 „	8·4				
	9.30 „	65 19	11 24 „	7·7	19·145	34·59	27.80	27.02
	10 „	65 22	11 35 „	8·0	19·185	34·66	27.85	27.02
	11 „	65 29	11 58 „	8·2	19·175	34·64	27.84	26.98
	Midn.	65 35	12 20 „	7·4	18·97	34·27	27.54	26.81
	29, 1 a.m.	65 40	12 24 „	8·5	18·975	34·28	27.55	26.65
	2 „	65 44	12 28 „	8·8	18·88	34·10	27.40	26.46
	3 „	65 49	12 32 „	8·2	18·95	34·23	27.50	26.65
	4 „	65 53	12 36 „	8·3	18·86	34·07	27.38	26.52
	5 „	65 58	12 40 „	8·2	18·915	34·17	27.46	26.62
	6 „	66 2	12 44 „	7·7	19·00	34·33	27.58	26.81
	7 „	66 7	12 48 „	8·0	19·005	34·34	27.60	26.78
	8 „	66 11	12 52 „	8·2	18·975	34·28	27.55	26.70
	9 „	66 16	12 56 „	8·2	18·93	34·20	27.48	26.64
	10 „	66 20	13 0 „	8·5	18·915	34·17	27.46	26.57
	Noon	66 28	13 8 „	8·55	18·875	34·10	27.40	26.50
	1 p.m.	66 30	13 25 „	8·5	18·86	34·07	27.38	26.49
	3 „	66 33	14 0 „	8·25	18·995	34·32	27.58	26.72
	5 „	66 36	14 34 „	8·0	18·875	34·10	27.40	26.59
	6 „	66 38	14 52 „	7·7	18·875	34·10	27.40	26.63
	8 „	66 41	15 26 „	7·0				
	9 „	66 43	15 44 „	7·4	18·67	33·73	27.10	26.38
	10 „	66 45	16 2 „	7·2	18·68	33·75	27.12	26.43
	11 „	66 46	16 21 „	7·7	18·485	33·40	26.84	26.09
	Midn.	66 48	16 40 „	7·9	18·44	33·31	26.77	25.99
	30, 1 a.m.	66 47	17 1 „	7·9	18·79	33·95	27.28	26.49
	2 „	66 45	17 22 „	7·9	18·79	33·95	27.28	26.49
	3 „	66 44	17 44 „	7·9	18·875	34·10	27.40	26.60
	4 „	66 43	18 5 „	7·9	18·72	33·82	27.18	26.39
	5 „	66 41	18 26 „	8·1	18·86	34·07	27.38	26.45
	6 „	66 40	18 47 „	8·2	19·04	34·40	27.64	26.79
	7 „	66 39	19 8 „	7·9	19·025	34·37	27.62	26.82
	8 „	66 38	19 30 „	8·4	19·00	34·33	27.58	26.70
	9 „	66 36	19 57 „	8·3	19·03	34·38	27.63	26.77
	10 „	66 35	20 12 „	8·2	19·06	34·43	27.67	26.82
	11 „	66 34	20 33 „	8·45	19·195	34·68	27.87	26.98
11	1 p.m.	66 33	21 3 „	8·55				
	2 „	66 32	21 34 „	8·65				
	3 „	66 31	22 5 „	8·5	19·175	34·64	27.84	26.94
	5.25 „	66 30	22 20 „	9·0	19·12	34·54	27.76	26.78
12	9 „	66 22	23 17 „	10·0	19·19	34·67	27.86	26.72
	10 „	66 15	23 30 „	10·4	19·155	34·61	27.82	26.61

1	2	3	4	5	6	7	8	9
Station	1900 Date and Hour	North Latitude	Longitude	Corr. Temp. of Sea Surf.	Cl. $^0/_{00}$	Salinity $^0/_{00}$	S $\frac{0}{4}$	S $\frac{t}{4}$
	July			^{0} C				
	30, 11 p.m.	66° 6′	23° 43′ W	10·75	18·91	34·16	27.45	26.19
	Midn.			11·65	18·435	33·31	26.77	25.37
	31, 1 a.m.	Dyra	Fjord	11·2	18·365	33·18	26.66	25.35
	August							
	2, Midn.	66° 7′	24° 40′ W	10·4	19·035	34·39	27.64	26.43
	3, 1 a.m.	66 11	24 55 „	9·4	19·115	34·53	27.75	26.71
	2 „	66 14	25 10 „	8·8	19·295	34·86	28.01	27.05
	3 „	66 18	25 25 „	8·7	19·32	34·90	28.05	27.11
	4 „	66 22	25 40 „	8·5	19·36	34·97	28.11	27.20
	5 „	66 25	25 55 „	8·7	19·395	35·04	28.16	27.22
	6 „	66 29	26 10 „	2·4	17·82	32·20	25.87	25.73
	7 „	66 33	26 25 „	1·7	17·59	31·78	25.53	25.44
	0.55 p.m.	66 44	26 45 „	1·45	17·095	30·89	24.82	24.75
	1.10 „	66 42	26 43 „	1·25	16·97	30·66	24.63	24.57
	4.55 „	66 42	26 40 „	2·75				
13	7 „	66 42	26 40 „	3·0	17·965	32·46	26.08	25.88
	7.30 „	66 40	26 30 „	4·25	18·215	32 91	26.44	26.12
	8 „	66 39	26 20 „	1·7	17·61	31·82	25.56	25.47
	9 „	66 35	25 29 „	1·8	17·51	31·64	25.42	25.32
	9.30 „	66 33'5	25 34 „	2·6	17·585	31·77	25.53	25.37
	10 „	66 32	25 39 „	2·6	17·46	31·55	25.34	25.19
	10.30 „	66 30	25 28 „	2·2	17·66	31·91	25.64	25.51
	11 „	66 28	25 18 „	6·3	18·51	33·44	26.87	26.31
	11.17 „			7·5	18·80*	33·96	27.29	26.55
	4, 0.15 a.m.			5·35	18·21*	32·90	26.43	25.99
14 b	1.20 „			4·55	18·10*	32·70	26.27	25.93
	1.40 „	66 28	25 18 „	9·4	19·335	34·93	28.07	27.02
14	3.10 „	66 28	25 18	—	18·69	33·77	27.13	26.11
	7 „	66 28	24 39 „	8·4	19·295	34·86	28.01	27.12
	8 „	66 28	24 20 „	8·3	19·28	34·83	27.99	27.11
	9 „	66 29	24 1 „	9·4	19·28	34·83	27.99	27.04
	10 „	66 29	23 42 „	9·5	19·27	34·81	27.98	26.91
	11 „	66 29	23 22 „	10·3	19·03	34·38	27.63	26.44
	Noon	66 29	23 3 „	10·3	18·95	34·23	27.51	26.32
	4.15 p.m.	66 24	21 33 „	8·85	19·17	34·63	27.83	26.88
	5 „	66 21	21 10 „	8·6	19·145	34·59	27.80	26.88
	6 „	66 17	20 47 „	8·8	19·06	34·43	27.67	26.73
	7.15 „	66 13	20 19 „	8·7	19·025	34·37	27.62	26.69
	8 „	66 10	20 0 „	8·81	18·965	34·26	27.53	26.59
	9 „	66 12	19 41 „	8·31	18·935	34·21	27.49	26.63
	10 „	66 14	19 22 „	9·1	18·755	33·82	27.18	26.20
	11 „	66 16	19 3 „	8·5	18·995	34·32	27.58	26.69
	Midn.	66 18	18 44 „	8·1	18·99	34·31	27.57	26.74
	5, 1 a.m.	66 20	18 25 „	8·4	18·82	34·00	27.32	26.45
	2 „	66 22	18 6 „	7·9	18·90	34·14	27.44	26.64
	3 „	66 24	17 47 „	7·8	18·93	34·20	27.48	26.69
	4 „	66 26	17 28 „	8·1	18·765	33·90	27.24	26.42
	5 „	66 28	17 9 „	7·7	18·54	33·49	26.91	26.15
	6 „	66 30	16 50 „	7·7	18·375	33·20	26.69	25.94
	7 „	66 33	16 31 „	6·4	18·565	33·54	26.95	26.37

1	2	3	4	5	6	7	8	9
Station	1900 Date and Hour	North Latitude	Longitude	Corr. Temp. of Sea Surf.	Cl. ‰	Salinity ‰	S $\frac{o}{4}$	S $\frac{t}{4}$
	August			°C				
	5, 8 a.m.	66° 36′	16° 12′ W	5·0	18 87	34·09	27.39	26.97
	9 „	66 39	15 58 „	5·7	18·835	34·03	27.35	26.85
15	10.40 „	66 45	15 36 „	6·8	18·755	33·88	27.23	26.59
	5 p.m.	66 53	15 25 „	7·4	18·745	33·87	27.22	26.50
	5.30 „	66 56′5	15 20 „	7·6	18·77	33·91	27.25	26.50
	6 „	67 0	15 14 „	7·7	18·735	33·85	27.20	26.44
	6.30 „	67 3′5	15 9 „	7·9	18·835*	34·03	27.35	26.56
16	7 „	67 7	15 3 „	7·5	18·78	33·93	27.26	26.52
	7.15 „	67 7	15 3 „	7·5	18·755	33·88	27.23	26.49
	8 „	67 12	15 0 „	7·7	18 72	33·82	27.18	26.42
	8.30 „	67 16	14 52 „	7·7	18·705	33·79	27.16	26.40
	9 „	67 20	14 45 „	7·7	18·73	33·84	27.19	26.43
	9.30 „	67 24	14 37 „	7·5	18·87*	34·09	27.39	26.65
17	10 „	67 28	14 30 „	7·5	18·84	34·04	27.35	26.61
	Midn.	67 30	14 25 „	7·4	18·81	33·98	27.31	26.59
	6, 1 a.m.	67 38	14 13 „	7·4	18·835	34·03	27.35	26.73
	2 „	67 45	14 2 „	7·0	18·97	34·27	27.54	26.86
	3 „	67 53	13 50 „	6·3	19·035	34·39	27.64	27.06
	4 „	68 0	13 38 „	6·1	19·055	34·42	27.65	27.10
	6 „	68 11	13 26 „	5·9	19·02	34·36	27.61	27.08
	7 „	68 16	13 20 „	5·5	18·96	34·25	27.52	27.04
	8 „	68 21	13 14 „	5·3	18·865	34·08	27.39	26.94
	9 „	68 26	13 8 „	4·45	18·985	34·30	27.56	27.20
	10 „	68 31	13 2 „	5·5	19·005	34·33	27.58	27.10
	Noon	68 42	12 50 „	5·5	19·07	34·45	27.68	27.20
	2 p.m.	68 53	12 30 „	5·8	19·11	34·52	27.74	27.22
	4 „	69 4	12 10 „	5·8	19·02	34·36	27.61	27.10
18	5.15 „	69 9	12 0 „	5·7	18·955	34·24	27.52	27.02
	7.30 „	69 9	12 0 „	5·7	18·955	34·24	27.52	27.02
	10 „	69 23	11 52 „	4·9	18·995	34·32	27.58	27.17
	11 „	69 31	11 48 „	4·9	19·07	34·45	28.68	27.27
	Midn.	69 38	11 43 „	5·5	19·135	34·57	27.78	27.30
	7, 1 a.m.	69 45	11 39 „	5·5	18·93	34·20	27.48	27.00
	2 „	69 52	11 35 „	4·7	18·915	34·17	27.46	27.08
	3 „	69 59	11 31 „	5·4	18·945	34·22	27.49	27.03
	4 „	70 6	11 27 „	5·5	19·015	34·35	27.61	27.13
	5 „	70 14	11 22 „	4·9	18·86	34·07	27.38	26.98
	6 „	70 21	11 18 „	4·9	18·865	34·08	27.39	26.99
	7 „	70 28	11 14 „	4·6	19·03	34·38	27.63	27.25
19	8 „	70 35	11 10 „	4·5				
19 a	10.30 „	70 37	11 3 „	4·52	18·98	34·29	27.55	27.18
	Noon	70 44	10 50 „	4·6	19·03	34·38	27.63	27.25
20	0.30 p.m.	70 47	10 40 „	4·6	19·01	34·34	27.60	27.22
	2 „	70 46	10 0 „	3·7	18·965	34·26	27.53	27.25
21	2.45 „	70 45	9 52 „	4·1	18·895*	34·13	27.42	27.10
22	3.40 „	70 45	9 35 „	3·6	18·90*	34·14	27.44	27.17
23	5 „	70 48	9 30 „	3·8	18·895	34·13	27.42	27.13
24	6 „	70 51	9 24	3·4	18·72	33·82	27.18	26.93
	7 „	70 55	9 20	3·35	18·695	33·77	27.13	26.89
	9 „	70 55	9 10 „	3·9	18·415	33·27	26.73	26.44
	8, 10.30 a.m.	70 55	8 28 „	4·0	18·395	33·23	26.71	26.41
25	11.15 „	Jan Mayen		4·2	18·435	33·30	26.75	26.43
	9, 1 p.m.	70 47	7° 50′ W	4·7	18·265	33·00	26.52	26.15

1	2	3	4	5	6	7	8	9
Station	1900 Date and Hour	North Latitude	Longitude	Corr. Temp. of Sea Surf.	Cl. ‰	Salinity ‰	S $\frac{\sigma o}{4}$	S $\frac{t}{4}$
	August			°C				
	9, 2 p.m.	70° 47′	7° 24′ W	4·8	18·71	33·80	27.16	26.77
	3 "	70 46	6 58 "	4·7	18·70	33·78	27.15	26.77
	4 "	70 46	6 32 "	4·8	18·87	34·09	27.39	27.00
	5 "	70 46	6 32 "	4·9	18·815	33·99	27.32	26.92
29	6 "	70 46	6 32 "	5·0	18·795*	33·95	27.28	26.86
	8.30 "			4·7	18·65	33·69	27.07	26.69
	10, 1 a.m.	70 46	6 26 "	4·55	18·80	33·96	27.29	26.93
	2 "	70 44	6 10 "	3·8	18·365*	33·18	26.66	26.38
	3 "	70 42	5 34 "	3·8				
30	4 "	70 40	5 8 "	6·8	19·32*	34·90	28.05	27.39
	5 "	70 37	4 50 "	6·5	19·27	34·81	27.98	27.36
	5.30 "	70 36	4 41 "	6·4	19·27	34·81	27.98	27.37
31	6 "	70 34	4 32 "	7·6	19·375*	35·00	28.13	27.36
	7 "	70 31	4 14 "	7·2	19·355	34·97	28.11	27.39
	7.30 "	70 29	4 5 "	7·7	19·39	35·03	28.15	27.36
32	8 "	70 27	3 56 "	7·4	19·375*	35·00	28.13	27.38
32 a	9.15 "	70 23	3 40 "	8·3	19·46	35·16	28.25	27.37
33 a	10.30 "	70 20	3 20 "	8·4	19·46	35·16	28.25	27.35
33 b	11.30 "	70 17	3 4 "	7·8	19·395*	35·04	28.16	27.36
33 c	11.45 " *	70 15	2 54 "	7·9	19·405	35·06	28.17	27.35
34 a	1 p.m.	70 15	2 30 "	8·5	19·46	35·16	28.25	27.34
34	2 "	70 15	2 30 "	8·5	19·46*	35·16	28.25	27.34
	3.30 "	70 15	2 30 "	8·4	19·455	35·15	28.25	27.35
	10.15 "	70 15	2 30 "	8·5	19·45	35·14	28.24	27.33
35	Midn.	70 13	2 10 "	8·7	19·455*	35·15	28.25	27.30
	11, 1 a.m.	70 11	1 40 "	8·5	19·455	35·15	28.25	27.34
36	2 "	70 8	1 10 "	8·4	19·465*	35·17	28.27	27.35
	3 "	70 6	0 40 "	8·2	19·465	35·17	28.27	27.40
37	4 "	70 3	0 10 "	8·3	19·47*	35·17	28.27	27.39
	5 "	70 1	0 18 E	8·5	19·47	35·17	28.27	27.35
38	6 "	69 58	0 46 "	8·8	19·47*	35·17	28.27	27.31
	7 "	69 56	1 13 "	7·9	19·455	35·15	28.25	27.43
39	8 "	69 53	1 40 "	8·1	19·455	35·15	28.25	27.40
	9 "	69 52	1 53 "	9·0	19·46	35·16	28.25	27.25
40	10 "	69 51	2 5 "	9·1	19·46	35·16	28.25	27.24
	Noon	69 49	2 30 "	8·2	19·41*	35·07	28.18	27.32
	3 p.m.	69 50	3 45 "	7·8	19·425	35·09	28.20	27.40
41	4 "	69 51	4 15 "	9·4	19·435*	35·11	28.22	27.16
42	6 "	69 51	4 45 "	9·0	19·455*	35·15	28.24	27.24
	8.40 "	69 51	4 50 "	9·6	19·425	35·09	28.20	27.11
	9.45 "	69 51	5 0 "		19·41	35·07	28.18	27.09
43	11 "	69 52	5 15 "	9·65	19·385	35·02	28.15	27.05
	12, 2 a.m.	69 52	5 15 "	9·6	19·36*	34·97	28.11	27.02
	9.15 "	69 51	6 25 "		19·42*	35·08	28.19	27.10
	11 "	69 50	7 15 "		19·36	34·97	28.11	27.02
	Noon	69 49	7 42 "		19·355	34·96	28.09	27.00
44	2 p.m.	69 46	8 0 "	9·7	19·41	35·07	28.18	27.07
45	6.25 "	69 42	8 53 "	9·7	19·38	35·01	28.14	27.03
46	13, 3 p.m.	69 13	10 40 "	10·4	19·14	34·58	27.79	26.58
	5.30 "	69 13	10 40 "	10·4	19·14	34·58	27.79	26.58
47	14, 10.45 a.m.	68 55	13 16 "	10·1	19·29*	34·85	28.00	26.83
	0.30 p.m	68 55	13 16		19·315	34·89	28.04	26.89
	4 "	68 34	14 6		18·955*	34·24	27.52	26.39

1	2	3	4	5	6	7	8	9
Station	1900 Date and Hour	North Latitude	Longitude	Corr. Temp. of Sea Surf.	Cl. $^0/_{00}$	Salinity $^0/_{00}$	S $\frac{0}{4}$	S $\frac{t}{4}$
	August			^{0} C				
48	18,	Ankenes, Ofoten		10·0				
50	8 p.m.	Havnes, Ofoten		10·3				
51	22, 7.45 „	Between Barøen and Lødingen		8·45	19·045	34·41	27.65	26.76
52	24, 0,15 „	Østerbotten in Porsanger Fjord		7·0	17·725	32·02	25.73	25.11
53	25, 10.30 a.m.	Porsanger Fjord at Kistrand		7·6	18·07	32·65	26.23	25.50
55	28, 9 „	Porsanger Fjord 4′ NE off L. Tamsø		6·6	18·53	33·48	26.90	26.30
56	4 p.m.	71⁰ 5′	26⁰ 16′ 5 E	6·6	18·99	23·31	27.57	26.95
57	29,	71 36	25 15 „	6·6	19·31	34·88	28.02	27.39
58	30, 9 a.m.	72 40	23 10 „	6·9				
	Noon	72 24	22 56 „	6·6	19·32*	34·90	28.05	27.42
	2 p.m.	72 11	23 27 „	6·3	19·31*	34·88	28.03	27.44
	3 „	72 4	23 43 „	6·4	19 30*	34·87	28.02	27.42
	4 „	71 57	23 58 „	7·0	19·285*	34·84	28.00	27.32
	5 „	71 51	24 14 „	6·8	19·30*	34·87	28.02	27.36
	8 „	71 30	25 0 „	7·1	19·27*	34·81	27.98	27.28
	September.							
	3, Midn.	71 37	22 50 „	6·7	19·28	34·83	27.99	27.35
	4, 4 a.m.	72 13	22 2 „	6·45	19·31*	34·88	28.03	27.42
	8 „	72 47	21 18 „	6·35				
	9 „	72 53	21 8 „	5·8	19·215	34·71	27.90	27.38
	10 „	72 59	20 59 „	5·2	19·18	34·65	27.84	27.39
59	11 „	73 4	20 50 „	5·3				
	2 p.m.	73 14	20 36 „	5·15	19·10	34·51	27.73	27.29
	3 „	73 23	20 23 „	4·9	19·01	34·34	27.60	27.19
	4 „	73 32	20 10 „	4·0	18·80	33·96	27.29	26.98
	5 „	73 42	19 57 „	3·6	18·715	33·81	27.17	26.90
60	5.30 „	73 47	19 51 „	3·5	18·755	33·88	27.23	26.97
	7 „	74 1	19 33 „	1·4	18·47	33·37	26.81	26.73
	8 „	74 10	19 20 „	1·3	18·46	33·35	26.80	26.73
61	8.30 „	74 6	18 50 „	1·3	18·35	33·15	26.64	26.57
	5, 6 a.m.	74 9	18 10 „	1·0	18·33	33·12	26.61	26.56
	7 „	74 12	17 30 „	1·6	18·60	33·60	27.00	26.91
	8 „	74 15	16 50 „	2·3	18·805	33·97	27.30	27.15
	8.50 „	74 15	16 50 „	4·0	19·095	34·50	27.72	27.41
62	9 „	74 15	16 50 „	4·35	19·175	34·64	27.84	27.50
	6 p.m.	74 15	16 12 „	5·2				
	7 „	74 15	15 36 „	6·0	19·37	34·99	28.12	27.57
	8 „	74 15	15 0 „	5·5				
63	9 „	74 15	15 0 „	5·55	19·395*	35·04	28.16	27.67
	6, 1 a.m.	74 15	15 0 „	5·2	19·37	34·99	28.12	27.67
	2 „	74 14	14 22 „	5·3				
	3 „	74 14	13 44 „	4·7	19·35	34·96	28.09	27.70
	4 „	74 13	13 6 „	4·7	19·38	35·01	28.14	27.74
	5 „	74 13	12 28 „	4·8	19·365	34·98	28.12	27.71
	7 „	74 12	11 50 „	4·8	19·39	35·03	28.15	27.74
	8 „	74 12	11 50 „	4·9	19·39	35·03	28.15	27.73
64	9 „	74 12	11 50 „	4,8				
	1 p.m.	74 4	12 2 „	5·6	19·40	35·05	28.16	27.66
	2 „	73 56	12 14 „	5·7				
	3 „	73 48	12 26 „	5·7	19·415	35·08	28.19	27.68
	4 „	73 40	12 37 „	5·8	19·415	35·08	28.19	27.66

1 Station	2 1900 Date and Hour	3 North Latitude	4 Longitude	5 Corr. Temp. of Sea Surf.	6 Cl. 0/00	7 Salinity 0/00	8 S $\frac{0}{4}$	9 S $\frac{t}{4}$
	September			°C				
	6, 5 p.m.	73° 29′	12° 45′ E	5·6	19·39	35·03	28.15	27.65
	6 "	73 18	12 53 "	5·65	19·415	35·08	28.19	27.68
	7 "	73 7	13 1 "	6·4	19·40	35·05	18.16	27.55
65	8 "	72 56	13 10 "	6·1	19·40	35·05	28.16	27.59
	7, 1 a.m.	72 47	13 7 "	6·2	19·38	35·01	28.13	27.55
	2 "	72 38	13 4 "	6·3	19·375*	35·00	28.13	27.54
	3 "	72 30	13 1 "	6·6	19·385	35·02	28.14	27.51
	4 "	72 22	12 58 "	6·6	19·38*	35·01	28.13	27.51
	5 "	72 14	12 55 "	5 7	19·38	35·01	28.13	27.63
	6 "	72 6	12 52 "	6·3	19·38	35·01	28.13	27.55
	7 "	71 58	12 50 "	6·5	19·385	35·02	28.14	27·52
66	8 "	71 58	12 50 "	6·55	19·375*	35·00	28.13	27.50
	2 p.m.	71 35	12 35 "	6·4	19·36	34·97	28.11	27.50
67	7 "	71 10	12 12 "	6·9	19·37	34·99	28.12	27.45
	11 "	71 1	12 8 "	7·0	19·385*	36·02	28.14	27.45
	Midn.	70 51	12 3 "	7·2	19·425*	35·09	28.20	27.48
	8, 1 a.m.	70 42	11 59 "	7·3	19·375	35·00	28.13	27.40
	2 "	70 33	11 54 "	7·5	19·385	35·02	28.14	27.38
	3 "	70 23	11 50 "	7·6	19.39	35·03	28.15	27.38
	4 "	70 14	11 45 "	7·0	19·39*	35·03	28.15	27.46
	5 "	70 5	11 41 "	7·5	19·395	35·04	28.15	27.40
	6 "	69 56	11 36 "	7·4	19·39	35·03	28.15	27.41
	7 "	69 46	11 32 "	7·9	19·375*	35·00	28.13	27.31
68	9 "	69 37	11 28 "	8·1	19·36	34·97	28.11	27.26

Appendix Table 2.

Observations at the Stations June—July, 1902.

Station 32.

1902 VI 25 (18.55—19.50) Sulenfjord (Søndmøre). 420 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	11·5	32·83	25·00
10	7·78	34·74	27·12
25	·19	·97	·40
50	·07	35·01	·455
75	·15	·09	·50
100	·17	·11	·51
150	·35	·15	·515
200	·38	·19	·545
300	·35	·18	·545
400	·22	·26	·63

Station 33.

1902 VI 26 (0.75—0.55) 62° 43′ N, 5° 25′ E. 100 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·3	33·56	25·965
10	8·66	·82	26·27
25	·16	34·01	·495
50	7·82	·44	·685
75	6·88	·97	27·44
100	7·28	35·16	·54

Station 34 a.

1902 VI 26 (9.30—10.30) 62° 53′ N, 4° 14′ E.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·74	34·19	26·385
25	8·73	·24	·685
50	·22	35·01	27·275
75	7·97	·18	·435
100	·98	·29	·52
150	·38	·26	·59
200	·02	·26	·64
300	6·45	·20	·67
400	·27	·17	·67

Station 34 b.

1902 VI 26 (23.40) Same position as Stat. 34 a.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
700	1·28	34·98	28·035

Station 35

1902 VI 27 (18.30—20.10) 62° 58′ N, 1° 56′ E. Ca. 1100 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·44	34·23	26·47
25	8·14		
50	·12	35·10	27·36
85	7·93	·28	·52
100	[8·13]	[·26]	[·46]
150	7·22	·25	·60
200	6·82	·23	·645
300	·39	·21	·69
400	5·58	·19	·775

Station 37.

1902 VI 29 (2.45—3.55) 62° 43′ N, 1° 26′ E. Ca. 750 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·34	34·26	27·53
25	8·83	35·17	·32
50	·48	·26	·44
75	·10	·26	·50
100	7·75	·26	·55
150	·29	·26	·615
200	6·79	·25	·665
300	5·29	·10	·745
400	3·03	34·95	·865

Station 38 a.

1902 VI 29 (16.0—17.10) 62° 30′ N, 1° 56′ E. 503 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·8	35·34	27·29
25	·57	·33	·30
50	8·77	·31	·415
75	·51	·31	·455
100	7·77	·27	·535
150	·27	·24	·575
200	6·89	·20	·61
300	·17	·17	·70
400	4·91	·08	·775

Station 38 b.

1902 VI 29 (22.0—22.30) Nearly same position as 38 a. 550 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·8	35·17	27·14
300	6·25	·17	·670
550	—0·07	34·96	28·09

Station 39.

1902 VI 30 (12.20—13.20) 62° 23′ N, 2° 35′ E. 400 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·4	34·24	26·425
25	7·74		
50	6·91	·70	27·22
75	·65		·435
100	7·55	35·22	·545
150	6·93	·16	·58
200	·83	·22	·645
300	·43	·20	·69
400	·11	·19	·78

Station 40.

1902 VI 3 (23.50) — *VII 1* (1.0) 62° 27′ N, 0° 55′ E

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·4	34·63	26·975
25	8·72	35·29	27·43
50	·08	·27	·515
75	7·82	·27	·545
100	·52	·26	·59
150	·06	·23	·625
200	6·76	·22	·655
300	5·89	·16	·71
400	2·80	34·97	·910

Station 41.

1902 VII 1 (8.30—9.30) 62° 33′ N, 1° 00′ W

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	9·34	35·10	27·17
25	·38	·09	·16
50	8·37	·27	·465
75	·09	·29	·53
100	7·77	·27	·555
150	·14	·24	·615
200	6·71	·22	·665
300	4·94	·07	·76
400	2·40	34·93	·905

Station 42.

1902 VII 1 (15.55—17.0) 62° 37′ N, 2° 36′ W

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	8·14	35·13	27·38
25	7·70	·12	·44
50	5·65	·01	·64
75	4·16	34·98	·785
100	3·50	·95	·820
150	2·65	·94	·895
200	1·73	·85	·89
300	0·95	·92	·955
400	0·54	·93	28·04

Station 43.

1902 VII 2 (9.55—10.47) 62° 28′ N, 5° 14′ W. 430 m.

M.	t^0 C.	$S\,^0/_{00}$	σ_t
0	8·64		
25	·55		
50	·15		
75	7·98	35.24	27·49
100	·78	·26	·54
150	·73	·24	·525
200	·60	·24	·545
300	·34	·23	·58
400	5·71	·12	·61

Station 46.

1902 VII 14 (2.35—3.55)
60° 54′ N, 4° 20′ E. 425 m.

M.	t° C.	S ‰	σ_t
0	10·40		24·54
10	·85	32·27	·68
25	7·22	34·51	27·03
50	6·27	·73	·32
75	·56	·97	·48
100	7·39	35·18	·525
150	·26	·20	·555
200	·21	·27	·625
300	6·51	·24	·69
400	·16	·19	·70
425	·05	·18	·715

Station 47.

1902 VII 14 (10.15—11.20)
60° 57′ N, 3° 42′ E. 355 m.

M.	t° C.	S ‰	σ_t
0	12·02	32·20	24·40
10	11·74	·22	·48
25	7·19	34·49	27·00
50	·16	35·04	·45
75	8·00	·27	·525
	7·98		
100	·73	·20	·505
150	·48	·20	·54
200	·28	·23	·58
300	6·57	·19	·65
350	·16	·15	·675

Station 48.

1902 VII 14 (17.50—18.40)
61° 00′ N, 2° 53′ E. 275 m.

M.	t° C.	S ‰	σ_t
0	10·81	33·77	25·87
10	·65	·81	·94
25	9·88	35·30	27·25
50	·02	·31	·395
75	8·83	·30	·415
100	·66	·31	·455
150	·40	·30	·48
200	·16	·28	·50
275	7·94	·29	·545

Station 49.

1902 VII 15 (3.50—4.20)
61° 03′ N, 2° 13′ E. 130 m.

M.	t° C.	S ‰	σ_t
0	10·47	34·05	26·155
10	·58	·06	·14
25	·28	·53	·57
50	8·26	35·15	27·385
75	7·86	·30	·57
100	·06	·28	·66
125	6·78	·26	·69

Station 51.

1902 VII 15 (19.10—20.55)
61° 40′ N, 3° 11′ E. 405 m.

M.	t° C.	S ‰	σ_t
0	10·8	33·04	25·29
10	·86	·17	·375
25	8·64	35.07	27·26
50	·76	·34	·46
75	·41	·34	·51
100	·37	·35	·53
150	·16	·34	·55
200	7·92	·29	·55
300	·23	·26	·625
400	6·34	·24	·715
„	·52	·25	·705

Station 52.

1902 VII 16 (2.30—3.20)
62° 01′ N, 4° 00′ E. 203 m.

M.	t° C.	S ‰	σ_t
0	10·0	33·93	18·78
10	9·89	·98	·81
25	·66	34·08	·865
50	7·15	·61	19·16
75	6·73	·79	·26
100	7·01	35·02	·385
150	·15	·18	·475
200	·09	·19	·48

Station 53.

1902 VII 16 (12.20—13.30)
62° 36′ N, 3° 21′ E. 362 m.

M.	t° C.	S ‰	σ_t
0	10·60		
10	·25	34·34	26·435
25	9·88	35·26	27·22
50	·95	·30	·24
75	·25	·31	·365
100	8·94	·36	·45
150	·32	·31	·505
200	·12		
300	7·05	·21	·61
360	6·54	·19	·66

Station 54.

1902 VII 16 (21.05—22.05)
62° 29′ N, 4° 52′ E. 201 m.

M.	t° C.	S ‰	σ_t
0	10·37	33·90	26·05
10	·38	·89	·04
25	9·99	·90	·11
50	7·01	34·82	27·30
75	·01	35·09	·515
100	·28		
„	·14	35·12	·515
150	·11	·23	·61
190	6·93	·22	·68

Station 55 a.

1902 VII 19 (4.10—6.15)
62° 40′ N, 1° 56′ E. 668 m.

M.	t° C.	S ‰	σ_t
0	10·0	35·28	27·185
200	6·61		
300	4·97	·08	·765
400	3·01		
500	0·53	34·97	28·08
600	— 0·14	·93	·07
670	— ·21	·91	·065

Station 55 b.

1902 VII 19 (9.55) Same position as Stat. 55 a.

M.	t° C.	S ‰	σ_t
650	—0·24	34·93	28·08

Station 56 a.

1902 VII 19 (16.0—17.30)
62° 23′ N, 2° 03′ E. 460 m.

M.	t° C.	S ‰	σ_t
0	10·15		
10	·14	35·22	27·125
25	·10	·21	·12
50	8·71	·28	·40
75	·35	·30	·47
100	7·81	·28	·485
150	6 98	·20	·59
200	·53	·17	·67
300	5·27		
400	3·23	34·99	·88
460	1·90	·92	·94

Station 56 b.

1902 VII 19 (20.15—20.25)
Same position as Stat. 56 a.

M.	t° C.	S ‰	σ_t
300	5·83	35·14	27·715
450	1·92	·94	·955

Station 59.

1902 VII 22 (morning)
62° 38′ N, 4° 40′ W. 650 m.

M.	t° C.	S ‰	σ_t
650	—0·45	34·97	28·135

Station 66.

1902 VII 27 (18.35)
62° 29′ N, 4° 12′ W.

M.	t° C.	S ‰	σ_t
625	0·99	34·96	28·04

Station 67.

1902 VII 27 (21.30)
62° 35′ N, 4° 04′ W. 622 m.

M.	t° C.	S ‰	σ_t
620	—0·03	34·92	28·075

Station 70.

1902 VII 29 (14.30)
62° 04′ N, 3° 38′ W. 865 m.

M.	t° C.	S ‰	σ_t
860	—0·40	34·96	28·11