REPORT ON HYDROGRAPHIC INVESTIGATIONS IN ALEUTIAN WATERS AND THE SOUTHERN BERING SEA IN THE EARLY SUMMERS OF 1953 AND 1954*

Seikichi MISHIMA and Satoshi NISHIZAWA

Faculty of Fisheries, Hokkaido University

I. Introduction

The training ship "*Oshoro Maru*" of the Faculty of Fisheries, Hokkaido Universty, has made cruises to the salmon fishery grounds in the northern part of the North Pacific and the southern Bering Sea near the Aleutian Islands in 1953 and again in 1954. The main purposes of these cruises were the drilling of cadets in navigational and fishery work, but use was made of the opportunity also to undertake oceanographic and biological researches. The results of the hydrographic investigations are dealt with in the present paper.

In the 1953 cruise the "*Oshoro Maru*" left her mother port, Hakodate, on 4th May, under the command of Captain Mishima (One of the authors) having aboard 34 crew members, 18 cadets, a chemist, a physicist and two students. During this voyage, on 18th July there happened an unfortunate accident that the No. 1 Oiler lost his life by the explosion of an air tank in the galley. On account of this unexpected event the ship had to hasten her homeward voyage abandoning the work of the original plan; she arrived at Hakodate on 22nd July. The approximate track of the ship and positions of the hydrographic stations in this cruise are illustrated in figure 1 whilst more exact locations of positions are given in Appendix.

In the 1954 cruise the ship left Hakodate on 25th May and returned there on 14th July, the track for this cruise having covered as far as Bristol Bay for practice in crab fishery (fig. 1). Captain Mishima and his 34 men, 15 cadets, an oceanographer and two students were on board the ship.

The locations of the hydrographic stations listed in Appendix were decided by position line sailing for the 1953 cruise, sometimes by merely dead reckoning under overcast sky, while on the 1954 cruise the Lo-Ran operation was adopted to get more exact positions regardless of weather conditions.

The occupation of the whole number of stations has taken so long a period, more than five weeks in the 1953 cruise and more than three weeks in 1954, that the data might be not satisfactorily valuable to ascertain the simultaneous features of the hydrography in the areas; limitation of studies is also due to inappropriate location and number of the hydrographic stations because of the unavoidable necessity of carrying out the

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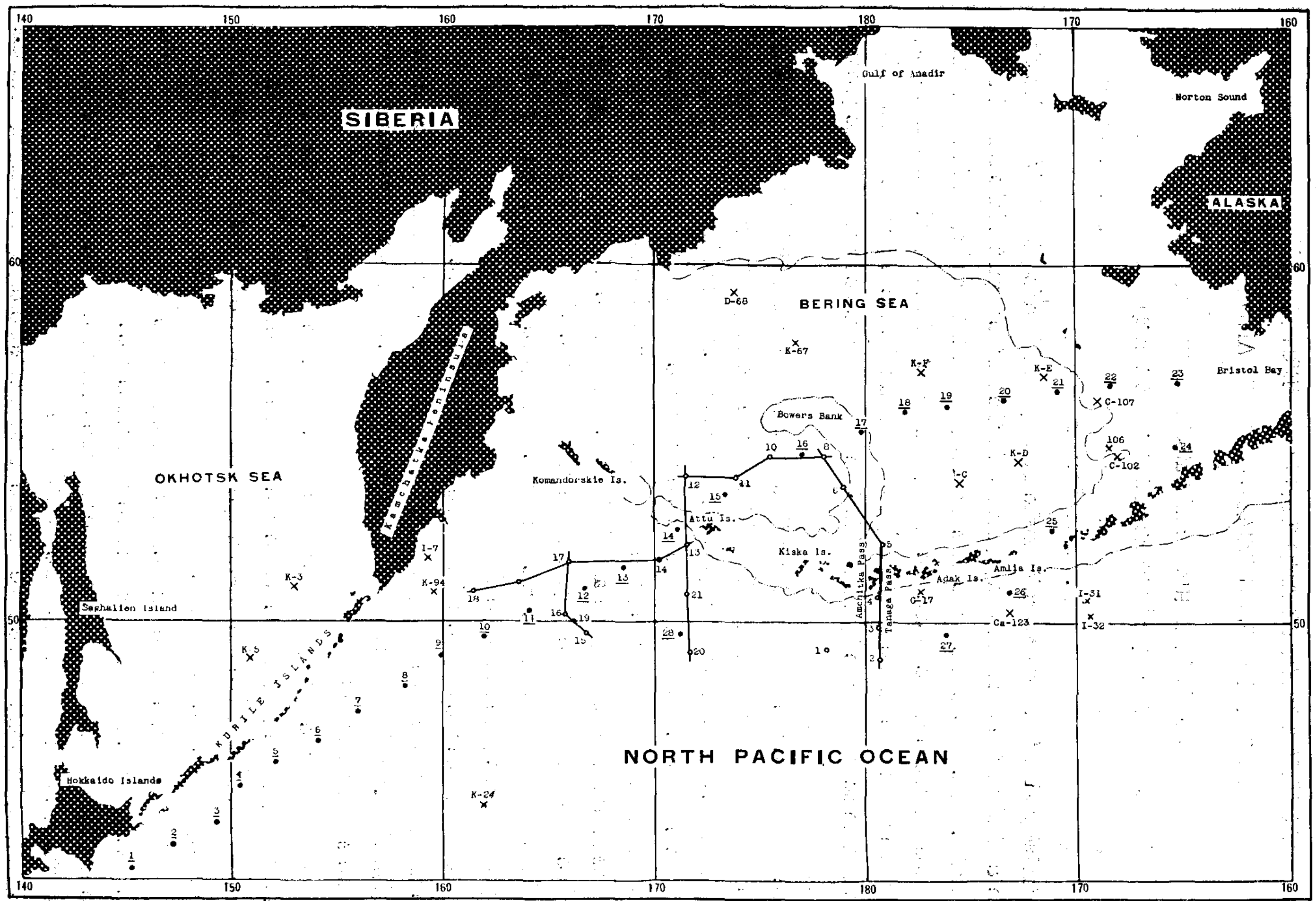

Fig. 1. Locations of the hydrographic stations occupied on the cruises of the *"Oshoro Maru"* to Aleutian waters and the southern Bering Sea in 1953 (shown with open circles) and 1954 (shown with solid circles)

Crosses show locations of some stations of previous cruises on *Komahashi* (K) in 1935 and 1936, *Itsukushima* (I) in 1935, *Gannet* (G) in 1933, *Chelan* (C) in 1934, *Carnegie* (Ca) in 1929 and *Dalinevastochinik* (D) in 1932; the materials taken at those stations on these cruises are referred to in the text.

other purposes of the cruises.

It is a pleasure to record here a debt of gratitude to Dr. Yoshitada Takenouti, the Director of the Hakodate Marine Observatory, for his kindness in criticizing the present data and in reading the original manuscript. The writers are much obliged to Assist. Prof. Hideto Koto of the University for his constructive criticism and helpful suggestions. They are also gratefully indebted to Prof. Naoichi Inoue and Prof. Sigeru Motoda of the University for their untiring encouragement and valuable suggestions throughout the course of the present investigations.

Particular thanks are due to Mr. Manichi Tochinai of the Fisheries Agency, Ministry of Agriculture, for his courtesy in providing many facilities for the present cruises. Thanks are also offered to the crew members, cadets, students and other people on board the ship, particularly to Mr. Masaomi Akagawa of the Hakodate Marine Observatory, for their hearty help during the work at sea. Their cordial thanks are also due to Miss Kyoko Shikauchi for her aid in salinity determinations.

II. General

The whole of the North Pacific above 30° north, as is well known, is dominated by the easterly flowing currents. The southern part of these currents carries warm Kuroshiwo water of high salinity while the northern part carries cold water of low salinity which is formed in successive whirls developed along the line of demarcation between the Kuroshiwo and Oyashiwo (Kurile) Currents. The latter part, comprised of so-called Subarctic Water of the North Pacific, divides into two branches when it strikes the coast of North America; the northern branch turns towards the north and flows into the Gulf of Alaska. It, then, diluted and heated in the Gulf, returns towards the west on the southern side of the Aleutian Islands (Sverdrup *et al.*, 1942; Sverdrdup, 1944). This returning flow has been ascertained by several Japanese vessels to continue as far west as to the westward of longitude 180° as has been shown in the "Current Chart of the North Pacific" compiled by the Hydrographic Office of Japan in 1936.

Along the eastern side of the Kamchatka Peninsula and northern Kurile Islands, a current of severely cold water of low salinity, probably formed in the preceding winter along some Asiatic coast, flows towards the south or southwest. One part of this current moves along the Pacific side of the Kurile Islands and there mixes with the water which has poured from the Okhotsk Sea into the Pacific through the Kurile Chain. It moves southwest along the southern side of Hokkaido Island, forming the so-called Oyashiwo Current. The intermediate layer of minimum salinity of the North Pacific, which is found down to depths below 300 m over almost the whole of the North Pacific except the region of the Subarctic Water, is formed by the subsurface mixing of the Kuroshiwo water from the south with the submerged Oyashiwo water from the north (Uda, 1935). Another part of this cold water, on the other hand, thrusts south directly into the Subarctic Water between longitudes 150° and 160° east, and spreads towards the east (Sverdrup, 1944). This severely cold water below 3° is found on either side of the Aleutian Islands as far east as longitude 175° west.

Waters of high temperature and low salinity extend over the shallow eastern region of Bering Sea especially in Norton Sound and Bristol Bay. In the northern part of the Bering, in the vicinity of the Gulf of Anadir, there originates abnormally cold water below 0° due to the severe winter cooling and ice melting. The deep portion of the Bering, however, is occupied by a water mass which is very much similar to the Subarctic water of the North Pacific. The general circulation of water in the Bering is counter-clockwise, and the shallow water from the Pacific pours into the Bering through any of the channels between the Aleutian Islands and sets east parallel to the chain of the Islands on the north side of it. In the eastern part of the Bering, waters moves north or northwest following the bottom contours of the eastern Bering. The warm water of low salinity found along the Alaskan coast moves also towards the north. These currents pass through the Bering Strait and finally pour into the Arctic Ocean (Barnes & Thompson, 1938; LaFond & Pritchard, 1952).

III. Temperature and Salinity

Vertical Distribution

The values of temperature and salinity obtained in the present observations in 1953 and 1954 are contained in Appendix, and in several vertical sections isotherms and isohalines are drawn in order to bring out the characteristic features.

As may be easily seen from these figures, in the shallow layers above 400 m the observations yield data within wide ranges in both temperature and salinity. The salinities increase very rapidly especially below 150 m, while in deeper layers, the observations converge on the characteristic values of the Subarctic Water of the North Pacific; salinity increase and temperature decrease with increasing depth are slow and uniform, attaining 2.6—2.9° in temperature and 34.4—34.5 ‰ in salinity at a level of 1000 m.

The homogeneous convection layer at the surface is very thin or can not be found at all in these regions during the period of the present investigations. The surface temperatures lie between 2.5° and 5.5°, and surface salinities between 32.8 ‰. With increasing depth, the temperature decreases rapidly at all stations, and salinity also decreases slightly at most of the stations down to about 100 m. The most conspicuous and interesting feature of stratification in these regions is the existence of a subsurface layer*

* The writers will, for convenience, use the terms ***the subsurface layer*** of minimum temperature for the cold layer below 3° found at a level of about 100 m, and ***the intermediate layer*** of maximum temperature for the warm layer found at a level of about 300 m.

of severely cold water of low salinity at about 100 m depth. The values of the minimum temperature of this layer in the present regions lie between 0° and 3°. Beneath the subsurface layer the temperature increases with increasing depth and at about 300 m level it reaches intermediate maximum values* above 3.5° followed by slow decrease below this level. The salinity, on the other hand, increases rapidly below the subsurface layer of minimum temperature and continues to increase slowly down to 1000 m level.

In Section I (stations 2 to 8, figs. 2-a and 2-b), which runs north and south in longitude 170° west, the surface water is very high in temperature and very low in salinity especially in the Pacific south of the Aleutian Ridge. At station 4 the temperature is above 5° and the salinity is below 33 ‰. The warm surface layer above 4° covers stations 2, 3 and 4 in the Pacific and station 5 in the Bering, but this layer vanishes to the north of station 5 in the Bering.

Below the topmost layer, the temperature decreases with increasing depth and shows a minimum at a level of approximately 100 m, except at station 5. The minimum, however, is not very pronounced, the lowest values being higher than 2.5°. It is of interest to note that the subsurface cold layer in the Pacific has higher temperatures and lower salinities than that of the Bering; the axis of the minimm temperatures in the Pacific has a temperature of 2.9° and a salinity of 33.2 ‰ at station 3, while the axis in the

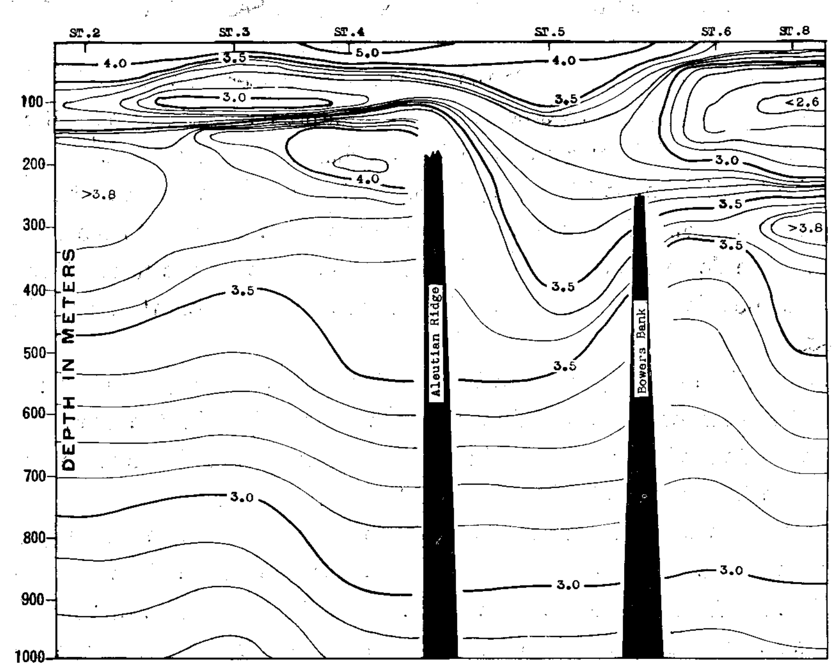

Fig. 2-a. Vertical distribution of temperature in Section I on May 15 to 18, 1953

* See the foot-note in p. 88

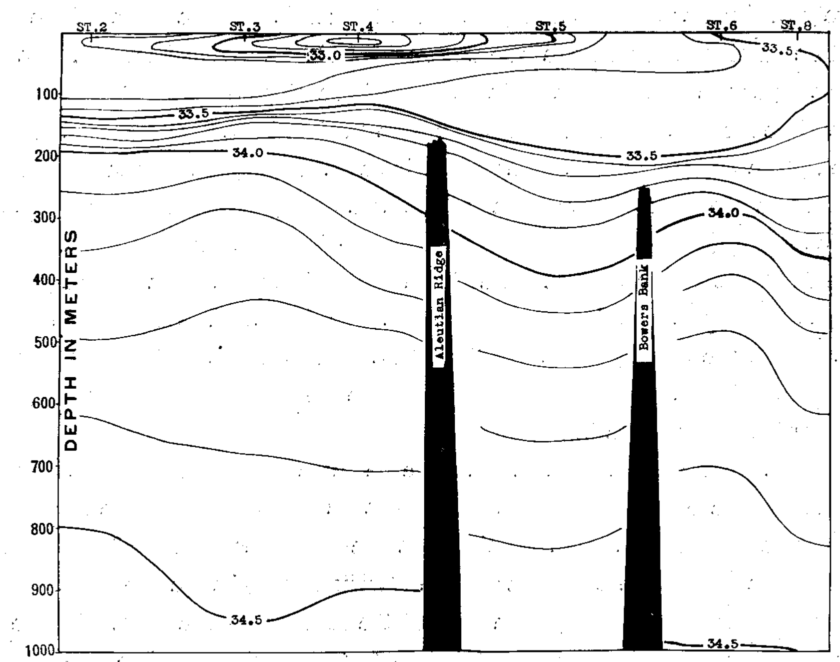

Fig. 2-b. Vertical distribution of salinity in Section I on May 15 to 18, 1953

Bering which sinks slightly towards the south has a temperature of 2.5° and a salinity of 33.4 ‰ at station 8. The water of low temperature below 3° in the Pacific, moreover, is very narrow in meridional extent and is very thin, having a thickness of only about 15 m, while that in the Bering is very thick, having a thickness of about 150 m.

At station 5, which is located very near to the ridge and also to the Bowers Bank, the temperature decreases slowly with increasing depth below the topmost layer; a minimum layer lies deep at 150 m level and is far less pronounced than at other stations in this section.

The subsurface cold layer in the Pacific does not show any distinct minimum of salinity but has rather higher salinities than the surface, but in the Bering several irregularities, intermediate minima and maxima, occur which indicate more or less complicated currents to the west of the Bowers Bank.

Below this level of minimum temperature, a rapid increase of temperature and salinity takes place within a short distance on either side of the ridge. At station 4, an intermediate maximum of temperature above 4° is found at a level of 200 m which, however, extends no farther to the north of the ridge. At station 3, the intermediate maximum is less pronounced than at station 4 and than at station 2 also, where a thick homogeneous layer of water higher than 3.8° but lower than 4° in temperature is found to lie between 150 m and 300 m levels. The intermediate layer of maximum temperature in the Bering lies deeper than in the Pacific and is less pronounced especially at station 5 where it lies deep at a level of 500 m, having a temperature of 2.5°.

The salinity increase below the subsurface cold layer is so much more rapid in the Pacific than in the Bering that the isohaline of 24 ‰ which lies at a level of 200 m in the Pacific suddenly sinks down to a level of 400 m to the north of the ridge approximately following the course of the isotherm of 3.5°. It is a conspicuous feature in this section that the isohalines of 34.20 ‰ and more as well as the isotherms of 3.5° and less below the layer of maximum temperature, rise towards the north between stations 2 and 3, and sink suddenly to the north of station 3, indicating that an accumulation of cold saline water takes place at station 3 and another accumulation of warm and less saline water takes place at station 4 down to a depth of about 900 m. This suggests the existence of a easterly current to the south of station 3 and a westerly current to the north of the same station.

The water below a level of 800 m decreases in temperature and increases in salinity gradually with increasing depth reaching about 2.8° of temperature and 34.5 ‰ of salinity at a level of approximately 1000 m in this section.

<u>In Section II</u> (stations 12, 13, 20 and 21, figs. 3-a and 3-b), which runs along the meridian in longitude 172° east, different features are found in the vertical distributions of temperature and salinity from those in the preceding section.

The surface temperature is lower than in Section I; the highest value 3.90° is found at station 21 where the surface salinity is 33.0 ‰, considerably higher than the surface value at station 4 in Section I. The surface temperature decreases to both sides of station 21, especially rapidly towards the north; to the north of the ridge, the surface temperature is below 3.2°. The surface salinity, on the contrary, increases to both sides of station 21, and at station 20 in the Pacific and at station 12 in the Bering it shows equally 33.30 ‰.

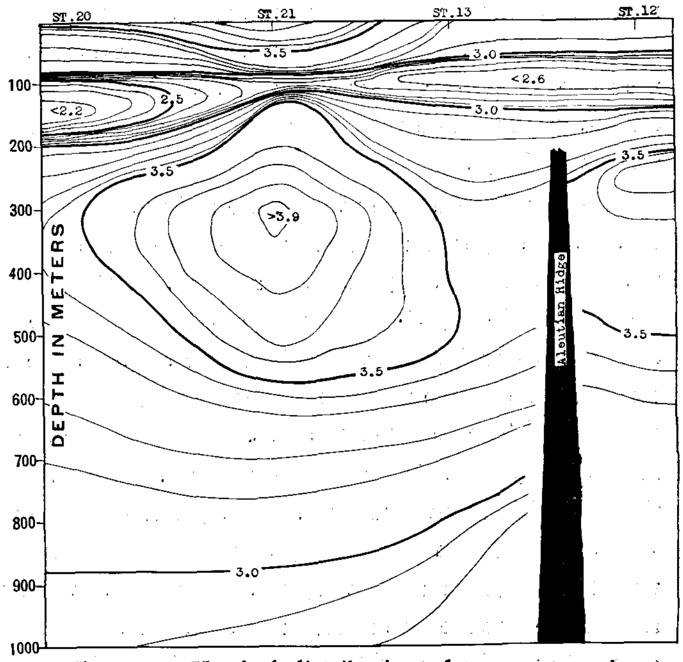

Fig. 3-a. Vertical distribution of temperature in Section II on May 20 to June 6, 1953

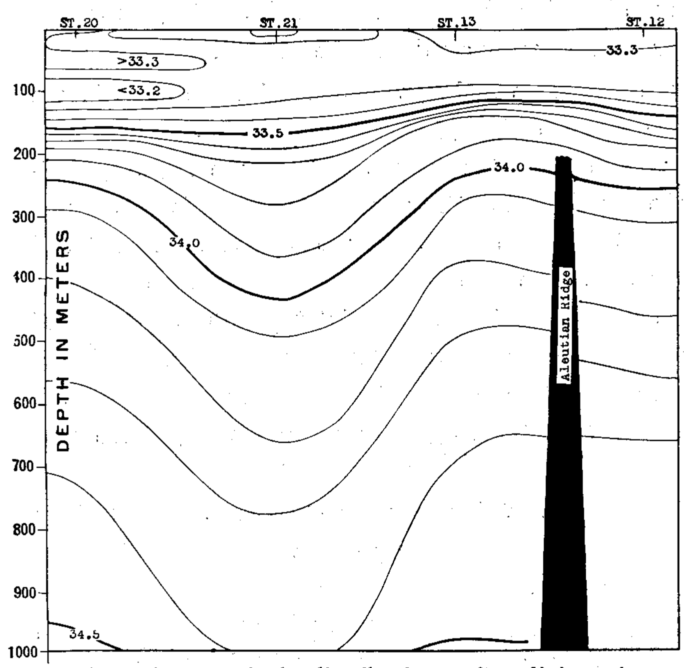

Fig. 3-b. Vertical distribution of salinity in Section II on May 20 to June 6, 1953

Remarkably developed subsurface cold layer below 3° is found through the section at a level of 100 m. At station 20 the subsurface minimum is especially well developed, having a value of 2.1°. The axis of minimum temperature rises towards the north between stations 20 and 21 increasing the minimum value itself. Towards the north from station 21, the axis runs approximately horizontally at a level of 100 m, and the minimum value again decreases slightly but remains above 2.5°. This subsurface layer of minimum temperature is also a layer of minimum salinity, in contrast to the preceding section, below 33.25 ‰ to the south of station 21 and below 33.28 ‰ to the north of the same station. On the Bering side of the ridge, however, a layer of homogeneous salinity of 33.30 ‰ is found to lie from the surface down to a depth of 100 m, and no minimum of salinity can be found in the subsurface cold layer.

Below this level, the temperature and the salinity increase with increasing depth; an intermediate layer of maximum temperature is met with at a level of about 300 m in the Pacific, considerably deeper than in Section I, and at a level of about 250 m in the Bering, considerably shallower than in Section I. The isotherms of 3.5° and more at station 21 show distinct upward curvatures above the maximum layer and downward curvatures below the maximum layer, forming a warm core at depths of between 200 m and 550 m. The center of the core is 3.94° in temperature and 33.83 ‰ in salinity, being slightly lower in both values than the warm center of the westerly current in Section I, which suggests that the westerly current above mentioned protrudes from station 4 in Section I, bending slightly south, and flows into the present section between stations 20 and 21 accompanied by the slight decreases in temperature and salinity. The axis of the intermediate maximum temperatures also sinks from east to west in accordance with the development of the subsurface cold layer. The distinct downward curvature of isotherms and isohalines below 300 m at station 21 indicates a marked downward transport of warm water down to a level of 1000 m or more. Thus, there occurs a considerable accumulation of light water at station 21, suggesting a development of a large whirl with its center at the station which rotates clockwise in the Pacific south of the ridge.

In Section V (stations 13, 14, 17, 18′ and 18, figs. 4-a and 4-b), which runs practically east and west between latitudes 51° and 52° north, the surface water higher than 4° in temperature covers the area between stations 14 and 17, and the surface temperature decreases to both sides. The surface salinity, on the other hand, is 33.30 ‰ at station 14 and 17, and increases to both sides. The surface layer higher than 3° in temperature is thinner than in the preceding two sections, and the thickness decreases from east to west, while the subsurface cold layer, the axis of which lies at 100 m level, increases in thickness from east to west, the minimum temperature itself rapidly decreasing.

The lowest temperature of the subsurface layer obtained in the 1953 cruise, 0.01°, is found at the westernmost station 18. At station 14, where a continuation of the warm core of the westerly current, found in Sections I and II, is met with at a level of 300 m, the minimum temperature in the subsurface cold layer is 2.82°, higher than at other stations in this section. The layer of minimum temperature in this section is also the layer of minimum salinity below 33.25 ‰ just as in Section II.

Below this level, the warm core above mentioned lies at a depth greater than 200 m

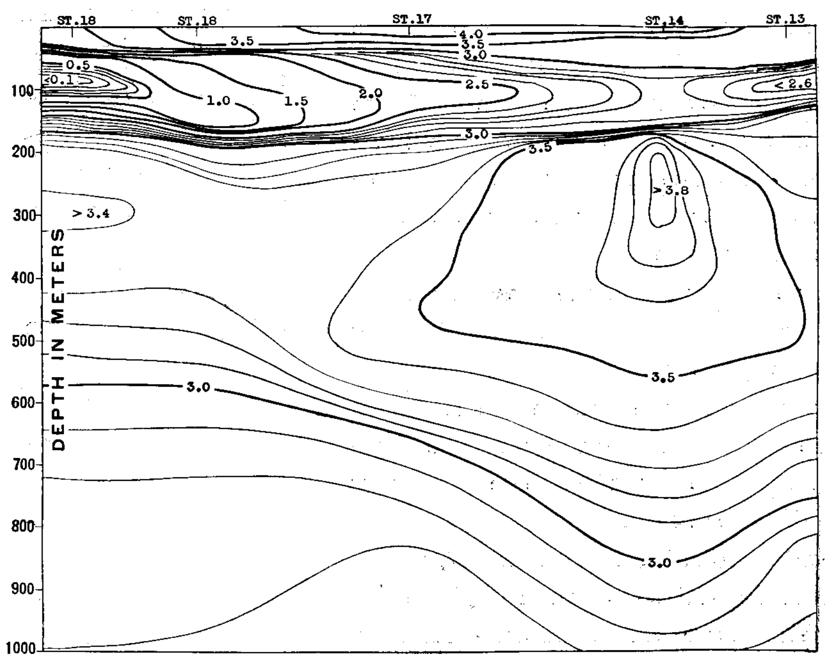

Fig. 4-a. Vertical distribution of temperature in Section V on May 20 to June 1, 1953

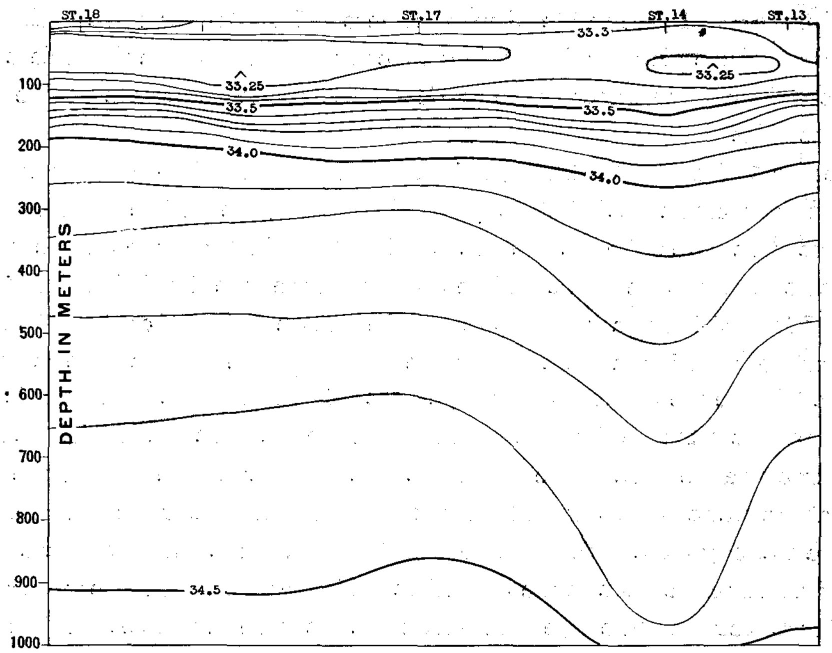

Fig. 4-b. Vertical distribution of salinity in Section V on May 20 to June 1, 1953

at station 14 and there is also found a remarkable downward transport of warm water as deep as 1000 m or more as in Section II. The large clockwise whirl, of which the vertical structure in the meridional direction has been noted in the preceding section, reveals its vertical structure in the east and west direction in this section.

It is noteworthy that in the western part of this section a distinct sinking of severely cold water below 1° takes place at station 18′ at a level of 150 m. At station 18 the intermediate maximum temperature is 3.42°, higher than the value at station 17, which suggests the existence of another current as discussed below.

In Section III (stations 15, 19, 16 and 17, fig. 5), which again runs north and south in longitude 166° east and bends at station 16 towards the southwest, the subsurface cold layer is especially developed at station 19 where the isotherms of 3° and less show a

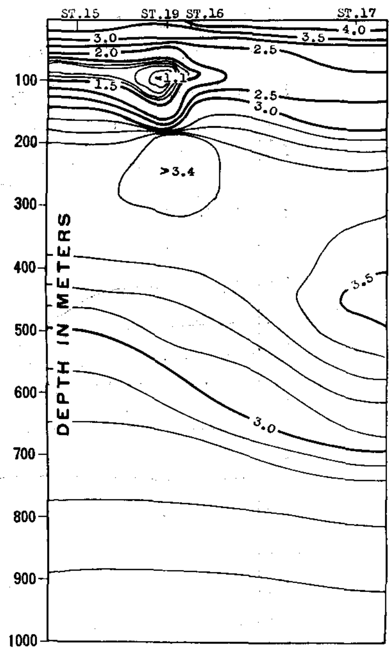

Fig. 5. Vertical distribution of temperature in Section III on May 24 to June 2, 1953

slight ascending motion of the cold water above a level of 100 m and a slight descending motion below this level. The values of minimum temperature increase to both sides, especially rapidly towards the north, from station 19.

At station 17 the western end of the warm core of the large clockwise eddy above mentioned is found at a level of about 450 m while another warm water mass above 3.4°, probably the continuation of the warm water found at an intermediate layer at station 18, lies just below the subsurfae cold layer at station 19. The isotherms of 3.3° and less rise towards the south especially rapidly between stations 17 and 16.

<u>In Section IV</u> (stations 12, 11, 10 and 8, figs. 6-a and 6-b), which runs practically east and west in the Bering parallel to the Aleutian Islands, no surface water is found above 4° in temperature which has always been met with in every previous section in the Pacific. At station 11, a remarkable ascending motion of cold subsurface water takes place resulting in low surface temperature below 3° and low surface salinity below 33.3‰. The surface salinity increases towards the east and at station

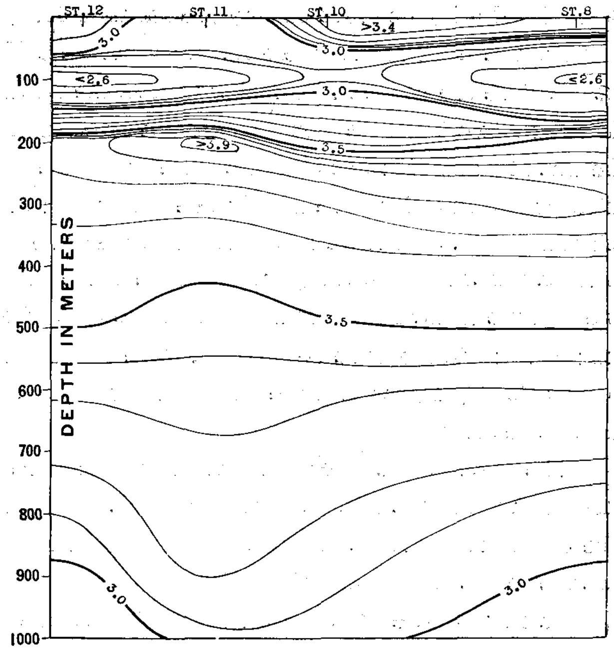

Fig. 6-a. Vertical distribution of temperature in Section IV on May 18 to 20, 1953

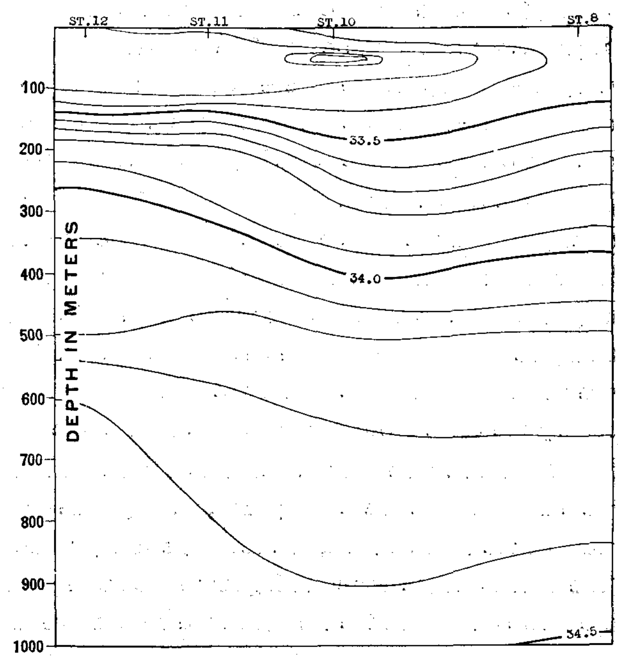

Fig. 6-b. Vertical distribution of salinity in Section IV on May 18 to 20, 1953

8, is found a high surface salinity greater than 33.5 ‰.

At a level of 100 m, there lies a subsurface cold layer, but the values of minimum temperature are above 2.5°, higher than at the Pacific stations in the previous sections. It is of interest to note that a subsurface layer of low salinity below 33.3 ‰ is found between 10 and 100 m at shallower levels than the subsurface cold layer; several irregular fluctuations in salinity are found there indicating more or less complicated currents. At station 10, the subsurface minimum of temperature is high being above 2.8° and the surface water has also a high temperature above 3.4°. Between stations 8 and 10 to the west of the Bowers Bank is found a unique spot where the water has a subaurface layer of minimum temperature below 2.6°. The salinity of this layer is above 33.4 ‰ which is considerably higher than the salinity values of the subsurface cold layer found in the Pacific sections.

The intermediate layer of maximum temperature in this section is also less pronounced than in the Pacific sections and the axis of maximum temperature sinks towards the east from 200 m depth at station 12 to 300 m depth at station 8, the maximum values themselves decreasing slightly.

Below this level, the isotherm of 3.5°, accurately following the isohaline of 34.20‰ rises towards the east between stations 12 and 11, and sinks very gradually to the eastward. But below a level of 600 m, the isotherm of 3.0° as well as the isohaline of 34.40 ‰ sinks below a level of 1000 m at stations 11 and 10, and then rises slowly as it proceeds towards the east. The isotherm of 3.0° in the Pacific sections, on the contrary, lies always above a level of 1000 m. These distributions indicate a descending movement below a level of 600 m; there is a suggestion of large clockwise rotation of the whole water body enclosed by the Aleutian Islands and the Bowers Bank.

In the cruise of the "*Oshoro Maru*" in 1954, twenty-eight stations were occupied; twenty-two of them were located along an extended section which, comprising stations 1* to 22, runs from off Hokkaido Island towards the east-northeast to Bristol Bay (fig. 1). The distributions of temperature and salinity in this whole section are shown in figures 7-a and 7-b. The section includes regions of different character. Therefore, the writers will first deal with the Central Part of the section which lies in approximately the same areas as that of the 1953 cruise, namely, stations 7 to 16.

General features of the vertical stratification in this part are almost similar to what were found in the preceding year excepting a few points. Waters in the Bering to the west of the Bowers Bank are found generally to be warmer and less saline than in 1953. The warm surface water of higher temperature than 4° was not found in the west of the Bowers Bank in the Bering in the 1953 cruise, but in this year, a thin surface layer

* The station numbers in the 1954 cruise shall be shown by underlined figures so as to be easily distinguished from the station numbers in the 1953 cruise.

Figure 7-a. Vertical distribution of temperature in the whole section covered on May 26 to June 8, 1954

Figure 7-b. Vertical distribution of salinity in the whole section covered on May 26 to June 8, 1954

above 4° in temperature and below 33.2 ‰ in salinity is found to extend from station 14 into the Bering Sea forming a very thin skin layer. The temperature of the subsurface cold layer in the Bering is also slightly higher and the intermediate layer of maximum temperature above 3.8°, being laid across the Aleutian Ridge, is developed much thicker than in the preceding year.

In deeper layers, the isotherm of 3.0°, which as well as the isohaline of 34.40 ‰ runs undulating up and down at levels between 600 m and 800 m in the Pacific, suddenly sinks below 1000 m in the Bering, indicating the occurrence of a higher development of downward transport to the west of the Bowers Bank in this year than in 1953.

The values of minimum temperature in the subsurface layer generally decrease from east to west in the Pacific with several irregularities which have resulted from successive whirls. This is the same tendency as was found in 1953. The subsurface layer of minimum temperature does not always have minimum salinity, but it is of interest to note that the subsurface cold waters at station 7, 8, 10 and 13, where the currents have more or less remarkable components directed towards the south as computed below, are lower in temperature than at the adjacent stations and have salinities which lie in the narrow range between 33.21 and 33.26 ‰. The low salinities of the subsurface layer of minimum temperature at stations 14 and 15 is apparently a result of the dilution by the fresh surface water of high temperature. At station 16 in the Bering the cold water which has similar character to the water found at station 8 in the 1953 cruise is met with in this year also.

The intermediate warm core of the large clockwise whirl in the Pacific which is similar to that found at station 14 in the 1953 cruise, lies at station 11 in this year.

Between stations 7 and 10, is found a homogeneous water mass which has a cold shallow layer below 1° in temperature and an intermediate layer of maximum temperature of about 3.45° at a level of 300 m. This water, which is very much similar to the water found at station 18 and 19 in the 1953 cruise seems dominantly to originate in the Bering as discussed below.

In the Southwestern part of the section (stations 1 to 6), the surface water decreases in salinity below 33.2 ‰ and increases in temperature above 2.0° towards the southwest, indicating that an accumulation of light water takes place in the shallow layers. The subsurface cold layer is very cold, below 1°, and a remarkable mass of cold water is found at stations 2 and 6. At station 6 the minimum values of the subsurface cold layer is 0.64°, the lowest temperature obtained in this year in the Pacific, although it is considerably higher than the lowest one of 0.01° obtained in the subsurface layer at station 18 in the preceding cruise. The difference, however, can not be attributed to annual variation only but may also be due to the deviation of geographical positions where the observations were taken. According to Uda (1935) the temperatures of the subsurface layer in these regions are considerably different from place to place according to the unhomogeneity of cooling effect in winter season in the area where this water has been originated.

The maximum temperature of the intermediate layer, decreasing from east to west, suddenly falls below 3° between stations 7 and 6, and at the latter is found a distinctly cold water mass lower than 2.5° down to a level of about 500 m. The isotherms as well as isohalines below a level of 100 m show remarkable downward curvatures at station 6. The same but less pronounced situation is found at station 2.

The intermediate layer of maximum temperature lies very deep between 400 m and 600 m, and the values of maximum temperature are lower than 3.0° except at station 4 where the temperature is slightly higher than 3° at a level of 400 m. The isohalines of 33.50 ‰ and above sink rapidly towards the southwest, indicating that the fresh water of the Oyashiwo Current flows south or southwest at station 1.

The remarkably cold water found in this area is considered to have come from the Okhotsk Sea through the Kurile Chain as discussed below. The conspicuous undulations of isotherms and isohalines in this area suggest a complicated development of the system of currents.

In the Eastern Part of the section, comprising stations 17 to 23, which runs practically west and east from the Bowers Bank to Bristol Bay in latitudes of 54° to 56° north, the general features are considerably different from those of the former regions.

The fresh water of Bristol Bay lower than 33 ‰ in salinity protrudes towards the west to station 21 in a shallow layer above 100 m, while the surface temperature increases westward from Bristol Bay attaining 5.3° at station 21, and then decreases towards station 18 where the value is below 4°. At station 16, it increases again above 4° but decreases again below 4° to the west of the Bowers Bank. The surface layer at station 20 has a uniform salinity of 33.4 ‰ down to a level of 100 m, which is the highest value found at the surface in the whole section. Proceeding towards the west, the surface salinity decreases below 33.2 ‰ at station 19 but increses again slightly at stations 18 and 17 to a point above 33.3 ‰.

In the subsurface depth, a distinct layer of minimum temperature is found to lie also in this region at a level of 150 m, which is deeper than in the western regions in both the 1953 and the 1954 cruises. The minimum values lie between 2.0 and 3.0° with increase towards the west from 2.0° at station 20 to 2.88° at station 17. The salinity, however, increases with greater depth below the surface; no minimum of salinity can be found in the subsurface layer of minimum temperature in which the salinity lies between 33.40 and 33.46 ‰.

In the central part of Bristol Bay, is found a severely cold bottom water below 0° with low salinity 31.20 ‰ just beneath the surface water of high temperature, but it seems not to spread out of the Bay beyond the continental shelf.

At a level of 300 m, there lies a layer of intermediate maximum temperature above 3.5° which stretches from the continental slope of Bristol Bay towards the west but never extends to the west of the Bowers Bank. The isotherm of 3.5°, above the maximum temperature, sinks as it proceeds towards the west from the continental slope; between stations 17 and 18 it sinks down suddenly to connect there with the isotherm of the same temperature which runs below the layer of maximum temperature undulating up and down, approximately following the isohaline of 34.20 ‰.

Below this level, isotherms rise towards the east along the continental slope, and isohalines, rising towards the east following isotherms between stations 18 and 20, sink, however, towards the continental slope to the east of station 20. At stations 20 and 21, a distinct accumulation of water of salinity higher than 34.4 ‰ is recognized which can not be found at other stations in the Bering above a level of 1000 m in the 1954 cruise. This extremely saline water seems to suggest an occurrence of upwelling in this area as discussed below.

Horizontal Distribution

The main features of the horizontal distribution of temperature and salinity have already been discussed to some extent; therefore, no details will be entered into but only the most important features will be pointed out.

Surface (figs. 8-a and 8 b) ………… In the observation of 1953, the warm surface water above 5.5° and of salinity lower than 33 ‰ is found at station 4 in the Pacific.

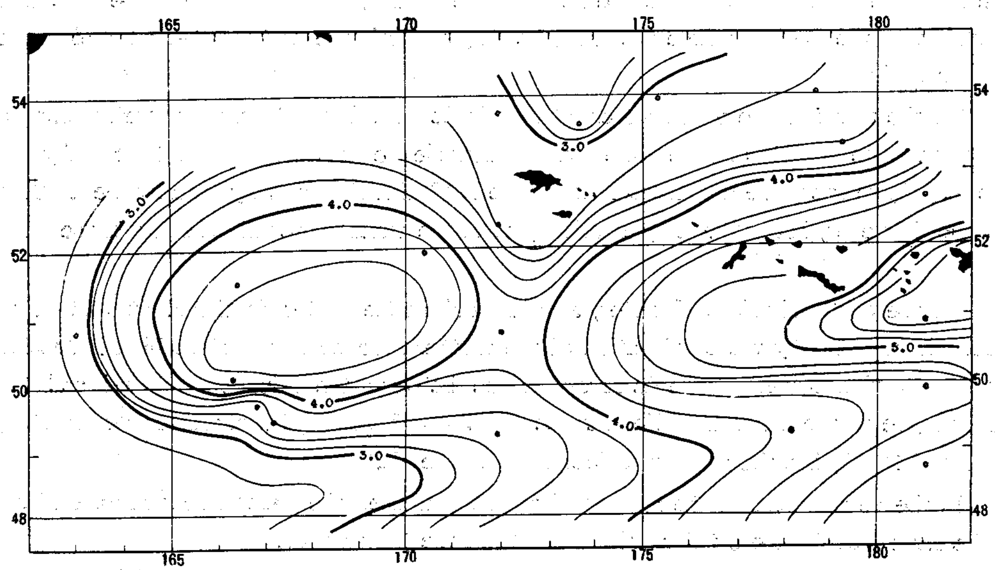

Fig. 8-a. Horizontal distribution of temperature at the surface on May 14 to June 6, 1953

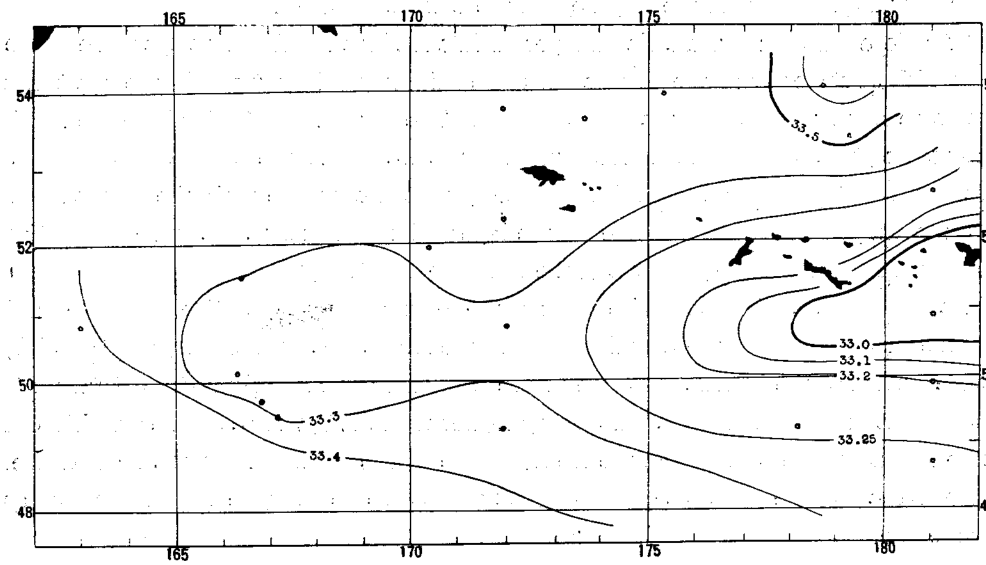

Fig. 8-b. Horizontal distribution of salinity at the surface on May 14 to June 6, 1953

This water extends towards the west along the Aleutian Islands decreasing gradually in temperature and increasing in salinity. To the west of longitude 165° east, however, no surface water is found higher in temperature than 4° and there occurs rapid decrease in temperature and rapid increase in salinty. The isotherms of 3.5° and higher as well as the isohalines of 33.30 ‰ and less extend farther north, passing through the Aleutian Islands into the Bering, where they run, bending towards the east, almost parallel to the islands chain.

To the south of the warm water, at a latitude of about 50° north, there is found a narrow tongue of cold surface water which protrudes east from station 18 rapidly increasing in temperature and crosses longitude 180° forming a very narrow belt. This tongue, however, has rather higher salinity than the warm water which flows to the north of it.

To the south of this cold water, a warm and saline water is found at station 2, which is undoubtedly the continuation of the northern branch of the Kuroshiwo Extension or the Aleutian Current. The demarcation line between the Aleutian Current and the cold tongue to the north of it lies between 47° and 45° north (Komahashi cruises in 1934, 1935 and 1936), but the present cruises do not cover it.

In the central part of the regions of the 1954 cruise, the general features are found to be not much differerent from those found on the 1953 cruise.

<u>One hundred-meter level</u> (figs. 9-a and 9-b) ………… Here the distribution of temperature is practically the same as at the surface. The cold water, protruded from the

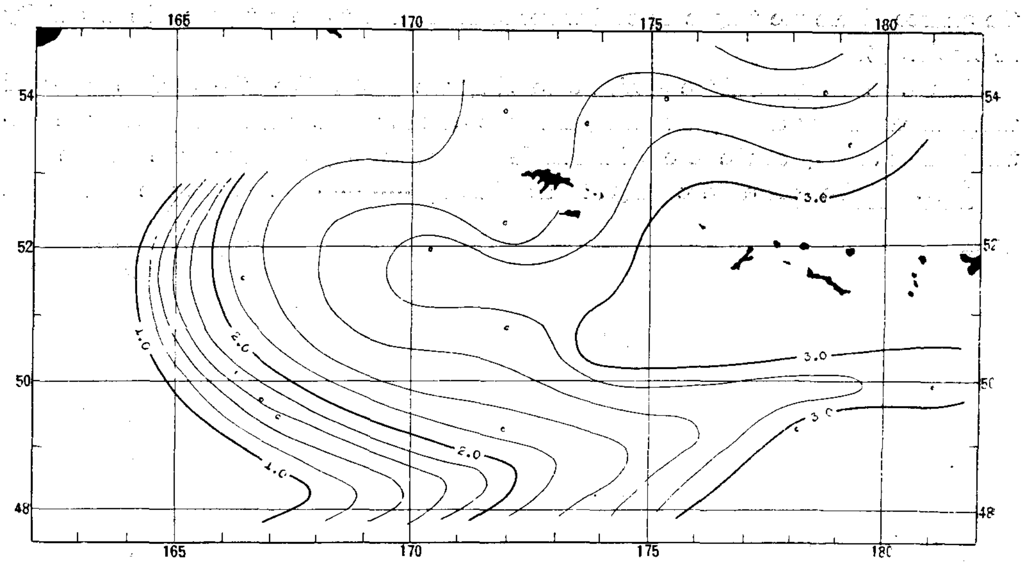

Fig. 9-a. Horizontal distribution of temperature at a depth of 100 m on May 14 to June 6, 1953

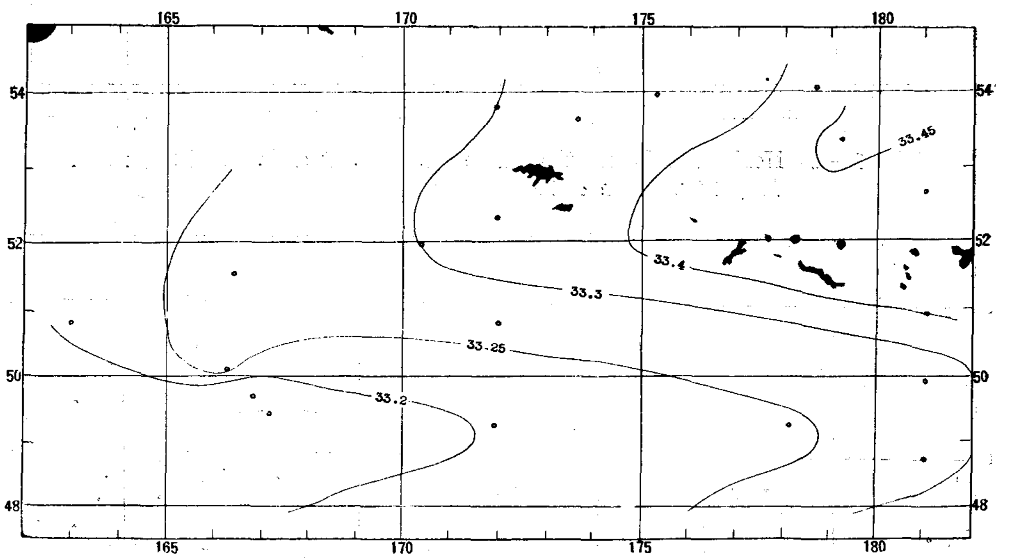

Fig. 9-b. Horizontal distribution of salinity at a depth of 100 m on May 14 to June 6, 1953

west, is found highly developed in this level and the temperature gradient is very great to the west of station 17 and to the south of station 15. As to the distribution of salinity, on the other hand, it is much different from the distribution at the surface; the warm water from the east increases but cold water from the west decreases in salinity with increasing depth, leaving the courses of the isohalines almost similar to those on the surface. Here the tongue of cold water is found also to be a tongue of low salinity below 33.3 ‰.

In the central part of the section covered by the 1954 cruise, the surface layer of warm water of low salinity extending from the east is thicker than in 1953 and the distribution of salinity at the level of 100 m depth is practically similar to the surface.

Three hundred-meter level (figs. 10-a and 10-b) ………… Here also, the distribution

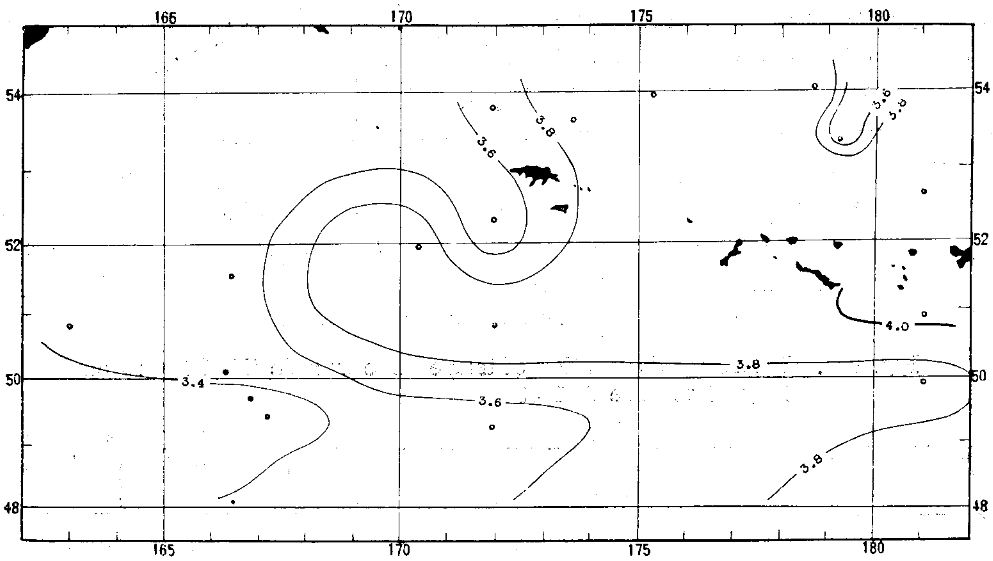

Fig. 10-a. Horizontal distribution of temperature at a depth of 300 m on May 14 to June 6, 1953

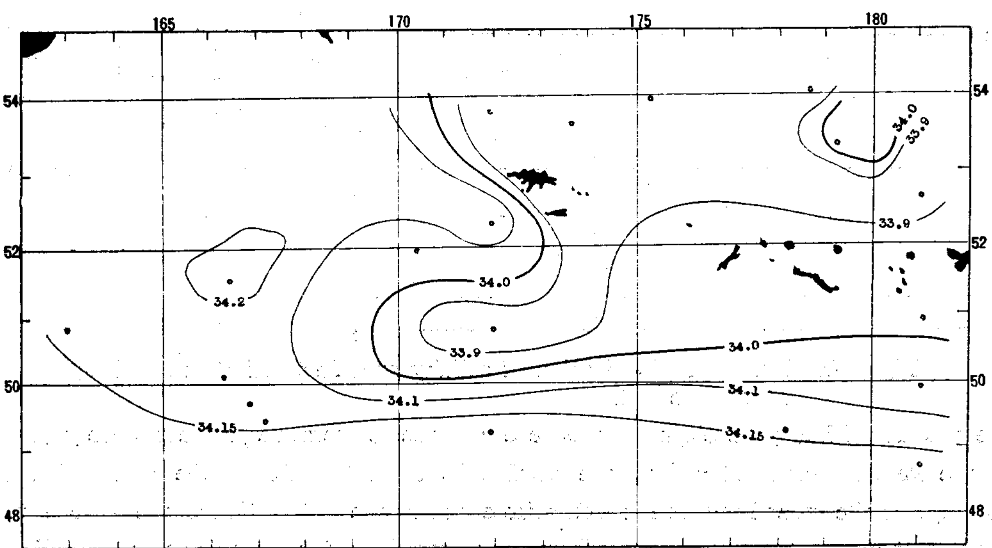

Fig. 10-b. Horizontal distribution of salinity at a depth of 300 m on May 14 to June 6, 1953

of temperature is almost the same as before, but, the temperature contrasts are smaller. The horizontal gradient in temperature to the west of station 18 is very small.

The distribution of salinity, however, is very different from that at 100 m level. The tongue of low salinity disappears and general increase in salinity towards the south takes place, resulting in approximately the same character of distribution as that of the surface.

The same character of temperature and salinity distribution as that for 300 m level can be found at the deeper levels though with still smaller contrast of values. The sction covered by the 1954 cruise shows especially that the Bering water from off Attu Island to the Bowers Bank is distinctly less saline and higher in temperature at deep levels than the Pacific water to the west of the Aleutian Ridge. Towards the western part of long section, temperature and salinity decrease with several irregularities and continue to the fresh and cold Oyashiwo water, while towards the eastern part of the section temperature decreases and salinity increases.

IV. Water Mass Analysis

As stated before, a distinct water mass of high temperature and low salinity is met with along the southern side of the Aleutian Islands. The temperature salinity diagrams for station 4 and 21 (fig. 11) shows the characteristic properties of this water at differnt levels and in different regions. Extremely low surface salinity suggests some coastal origin of this water. Barnes & Thompson (1938) found similar water at *Gannet*-stations

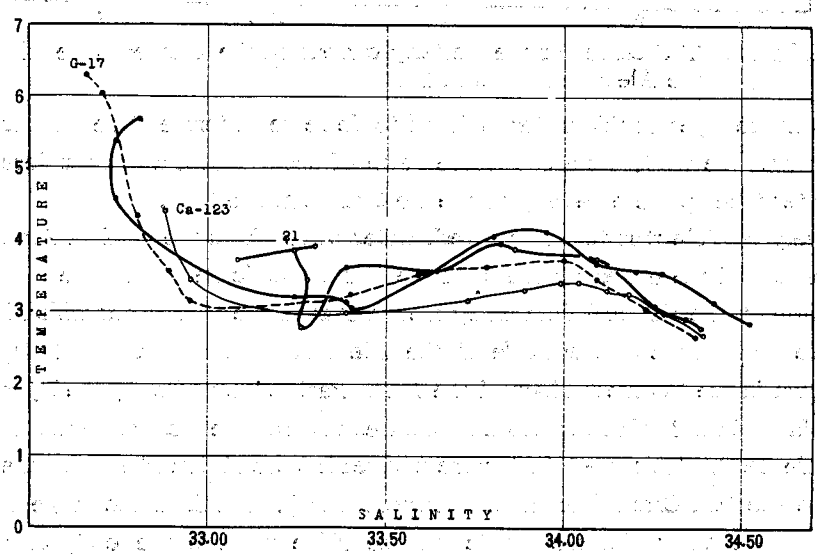

Fig. 11. T-S curves of the westerly current on the southern side of the Aleutian Islands in 1953. The T-S relations at *Gannet*-station 17 and at *Carnegie*-station 123 are also included. Locations of stations are shown in figure 1.

16 (51-12 N, 177-14 W) and 17 (50-55 N, 177-10 W) to the south of Adak Island in June 1933 (fig. 11), and ascertained the northward movement of this water by the computation of dynamic meters above 1000 m level. This water, however, differs apparently from the water of the Aleutian Current which is considerably lower in temperature and higher in salinity as characteristically represented by T-S curve for *Carnegie*-station 123 (50-27 N, 172-51 W) as included in the same figure. In the 1954 cruise, similar water is found at station 26 to the south of Amlia Island (fig. 12). In both 1953 and 1954,

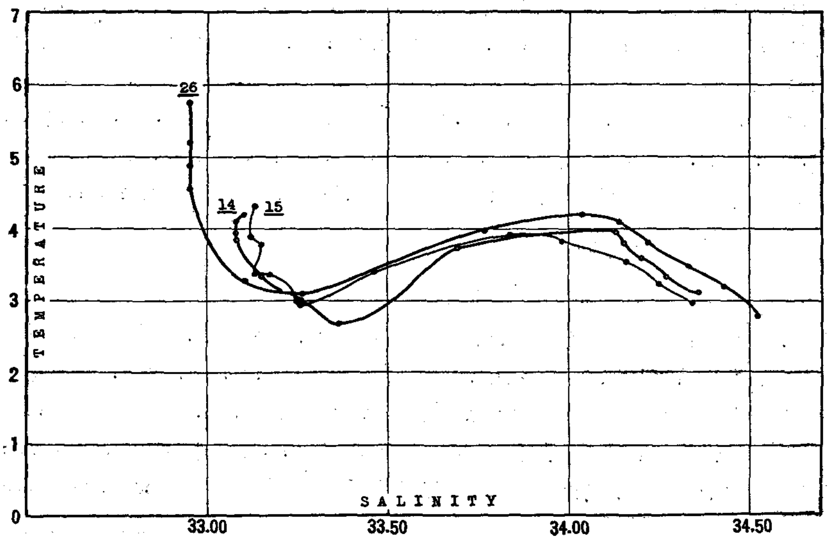

Fig. 12. T-S curves of the westerly current on the southern side of the Aleutian Islands in 1954

the fresh surface layer of this water is found to decrease in temperature and increase in salinity towards the west. At a subsurface depth of about 100 m, a distinct development of cold water takes place especially to the west of longitude 180°.

It is very possible that this warm fresh water comes from the Gulf of Alaska. The northern branch of the easterly currents of the North Pacific bends into the Gulf; there it is submitted to heating and dilution by fresh water of the Gulf, after which it returns towards the west on the southern side of the Aleutian Islands (Sverdrup, 1944). It is clearly shown in the "Current Chart of the North Pacific" compiled by the Hydrographic Office of Japan in 1936 that this branch continues towards the west as far as to the west of longitude 180°. This westward current spreads several branches into the Bering through the Aleutian Chain (Barnes & Thompson, 1938). North of the ridge near Bogoslof Island, currents which are parallel to the ridge towards the east, swing north following the bottom contours of the continental shelf (Barnes & Thompson, 1938). Thus there is found in the Bering at station 24 of the 1954 cruise a practically identical water to that of the warm current to the south of the Aleutian Islands (fig. 13).

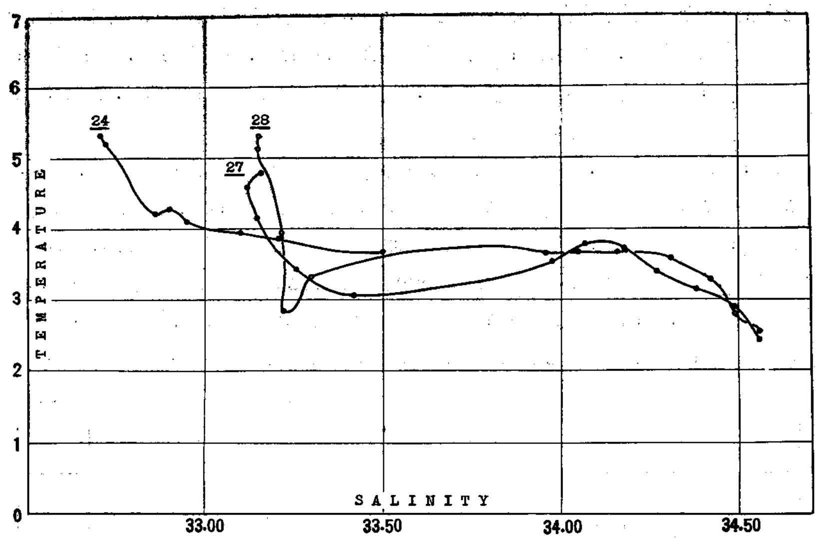

Fig. 13. T-S curves at station 24 to the north of Akutan Island and at stations 27 and 28 to the south of latitude 50° north in the Pacific in 1954

The character of the cold water mass which protrudes from west to east along the southern border of the warm water just described is represented in figure 14, in which

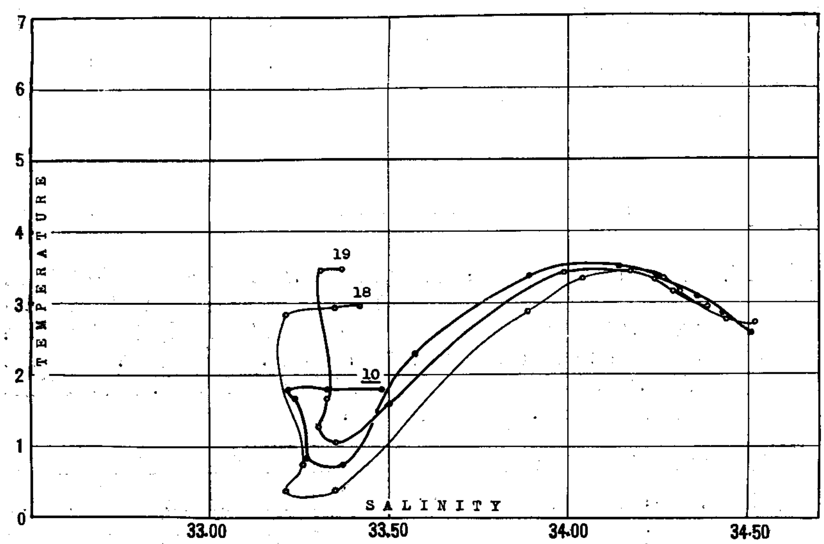

Fig. 14. T-S curves of the cold water of Bering origin obtained in 1953 and 1954

are included T-S diagrams for stations 18 and 19 of the 1953 cruise and for station 10 of the 1954 cruise. That cold water mass has a distinct layer of both minimum temperature below 1° and minimum salinity below 33.3 ‰ at a level of 100 m, whilst the surface salinity is high being above 33.3 ‰. At deeper levels the temperature is lower by 1 to 2° and the salinity is slightly higher than that of water to the immediately northward.

The source of cold water found in these regions is considered to lie in some area of intensive winter cooling along the Asiatic coast. Barnes & Thompson (1938) have inferred that the Okhotsk Sea, the Gulf of Anadir and the Kamtchatka Peninsula are possible sources. The character of cold water which moves south along the eastern coast of Kamtchatka in the season of present investigation is indicated in T-S diagrams in figure 15, using the data obtained at *Komahashi*-station 94 (50-39 N, 159-27 E) on her

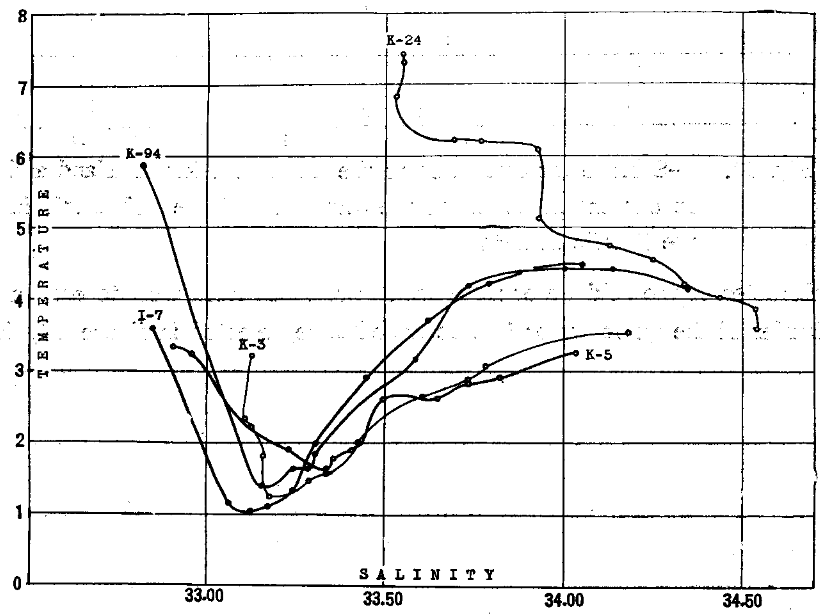

Fig. 15. T-S relations of the Okhotsk water at *Komahashi*-stations 3 and 5 in May 1935 and at *Komahashi*-station 94 in September 1935 and *Itsukushima*-station 7 in July 1935 to the southwest of Kamtchatka. The T-S relations of the Subarctic Water at *Komahashi*-station 24 is also included. Locations of stations are shown in figure 1.

cruise of September 1935 and at *Itsukushima*-station 7 (51-54 N, 159-18 E) on her cruise of July 1935. The T-S diagrams for the Okhotsk water are also included in figure 15 using the data obtained at *Komahashi*-stations 3 (50-45 N, 153-16 E) and 5 (48-39 N, 150-55 E) on her cruise of May 1935. The locations of these stations are indicated in figure 1. Shallow waters in these regions are practically alike, but the deep water below 100 m level in the Okhotsk is distinctly lower in temperature as well as in salinity than that it is off the Kamtchatka Peninsula, and the latter is very much the same as the deep water at stations 18 and 19 of the 1953 cruise and at station 10 of the 1954 cruise. Shallow water of these stations of the present cruises is a little higher in salinity than that of the two cold regions, and it is probably due to the mixing with the Subarctic Water near the surface. The T-S diagram for the Subarctic Water which flows towards the east or northeast just to the south of this cold water is likewise given in figure 15, using also the materials obtained at *Komahashi*-station 24 (43-34 N, 162-14 E) on her cruise of June 1935.

Thus, it may be said that the cold fresh water found stretching towards the east to form a very narrow belt in latitude 50° north originates mostly in the shallow region along the Siberian coast in the Bering and that it moves southward along the coast of Kamtchatka. A branch of this current bends east from the southern end of that peninsula and flows along the Aleutian Ridge. Another branch moves further south or southwest along the Kurile Islands. The latter branch, mixed with the cold water of the Okhotsk Sea which has poured into the Pacific through the Kurile Chain, meets there the warm extension of the Kuroshiwo Current (Subarctic Water), and is deflected sharply northeast to rejoin the former branch. This narrow belt, stretching towards the east, can be traced as far as longitude 170° west by the characteristic development of the subsurface cold layer found at *Itsukushima*-stations 31 (50-57 N, 169-14 W) and 32 (50-37 N, 169-14 W) in her cruise of July 1935 (fig. 16).

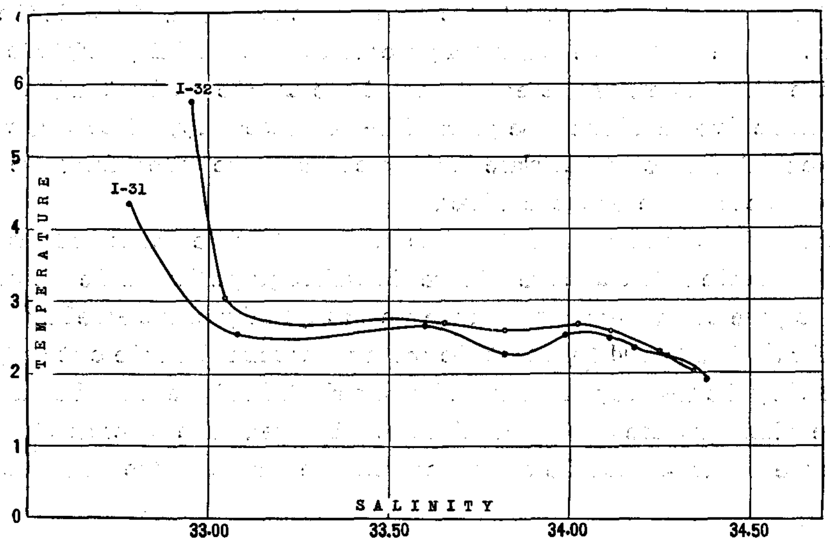

Fig. 16. T-S curves of the continuation of the narrow tongue protruded from west to east to the immediately north of the Subarctic Water; the materials taken at *Itsukushima*-stations 31 and 32. Locations of stations are shown in figure 1.

The water found at stations 1 to 5 of the 1954 cruise has a little different character; typical T-S relation for this water is shown in figure 17 which containes T-S diagram

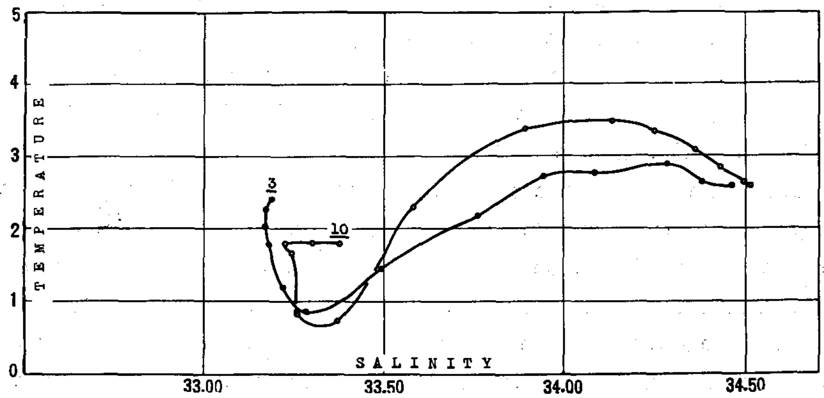

Fig. 17. T-S diagram of the water of Okhotsk origin to the south of the southern Kurile Islands (3). T-S diagrams of the water of Bering origin (10) is also included for comparison.

for station 3. In the same figure is included the T-S diagram for station 10 for comparison. The water at station 3 is apparently lower in temperature as well as in salinity than the water at station 10 especially at deep levels below 100 m, and it is more alike to the water of Okhotsk origin than to the water of Bering origin. Thus, in the southwestern area of the 1954 cruise is found a water mass which probably originates dominantly in the Okhotsk Sea. At several stations, however, the dominant origin of each water cannot be determined from the point of T-S character only, which suggests that an intensive mixing process takes place in this area among the waters from the Bering Sea, Okhotsk Sea and the Subarctic Water.

Water found at statations 1, 3, 13 and 20 in the 1953 cruise and at stations 11, 12, 13, 27 and 28 in the 1954 cruise are mixtures in various proportions of the two dominant water masses; the cold water mass from the west as typically characterized by the T-S diagrams for stations 18 and 10, whilst the warm water mass from the east as typically characterized by the T-S diagrams for stations 4 and 26. In figures 18 and 19 are shown the T-S relations for some stations of this mixed character. The water at station 2 is formed on the border between the cold water from the west and the Subarctic Water (fig. 20).

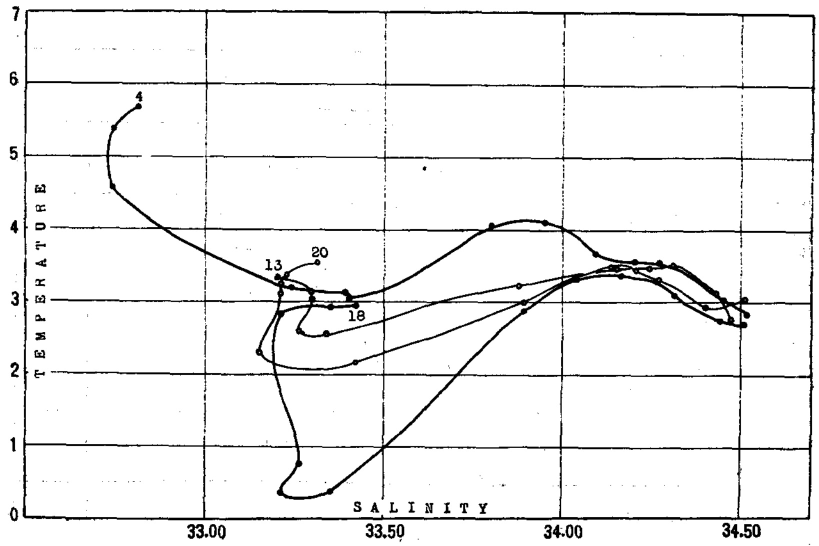

Fig. 18. T-S diagrams of the waters formed by mixing of two dominant water masses; the warm water from the east (4) and the cold water from the west (18), in 1953

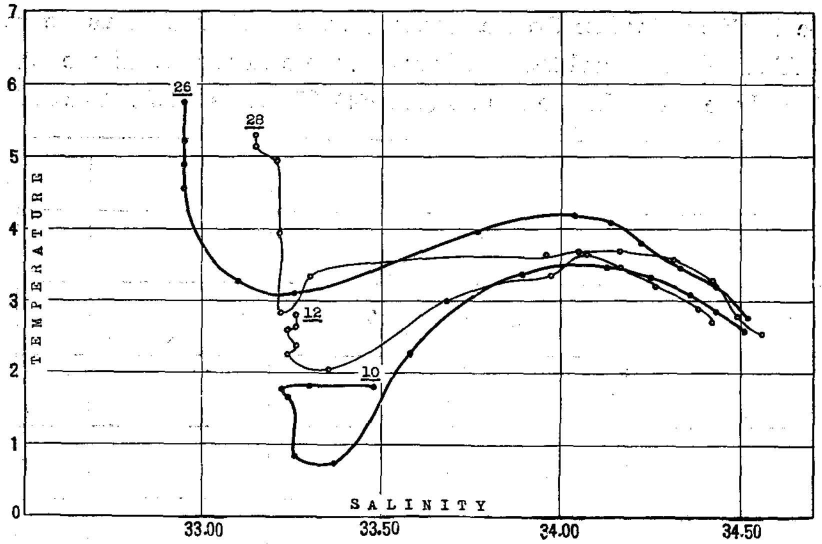

Fig. 19. T-S diagrams of the waters formed by mixing of two dominant water masses; the warm water from the east (26) and the cold water from the west (10), in 1954

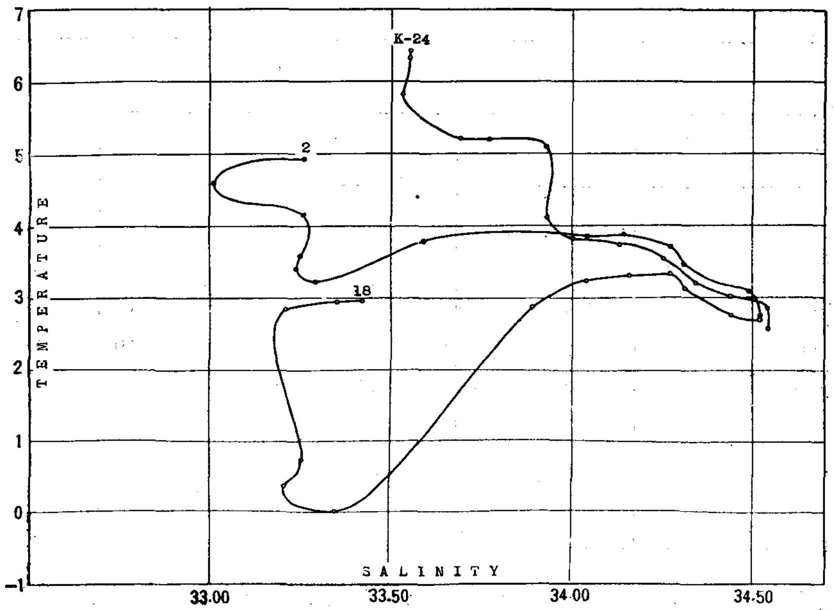

Fig. 20. T-S relation of the water formed on the border between the Subarctic Water (K-24) and the cold water of Bering origin(18)

North of the Aleutian Ridge near Attu, the character of the water is practically identical with that of the water just to the south of the ridge, indicating a northward flow of the Pacific water into the Bering through the shallow channels between Attu and Kiska Islands (in 1953 and 1954) and through the eastern part of the channel between Attu and the Komandorskie Islands (in 1954) (figs. 21 and 12). The shallow layer

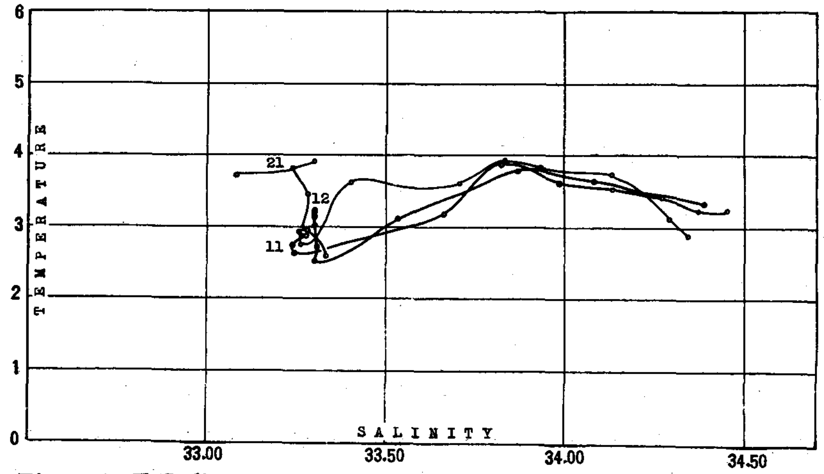

Fig. 21. T-S diagrams at stations to the immediately north of the Aleutian Islands in the Bering. T-S diagram at station 21 to the south of the Aleutian Islands in the Pacific is also included for comparison.

for stations 11 and 12, however, lacks such a marked stratification as found at station 21 in the Pacific and has a uniform vertical distribution of temperature and salinity, probably suggesting that the water from the Pacific suffers some agitation while passing through the shallow channel (fig. 21). The deep water below 100 m for stations located to the north of the ridge is somewhat higher in temperature and lower in salinity than the deep water found to the south of the ridge (figs. 12 and 21); this indicates that there occurs a downward transport of the shallow water which has entered into the Bering from the Pacific, after passing through the channels, as described above.

At stations 6 and 8 of the 1953 cruise and station 16 of the 1954 cruise, all of which are located to the west of the Bowers Bank, it is found that surface layers have high salinity above 33.5 ‰ in 1953 and above 33.3 ‰ in 1954 (fig. 22). Moreover, the

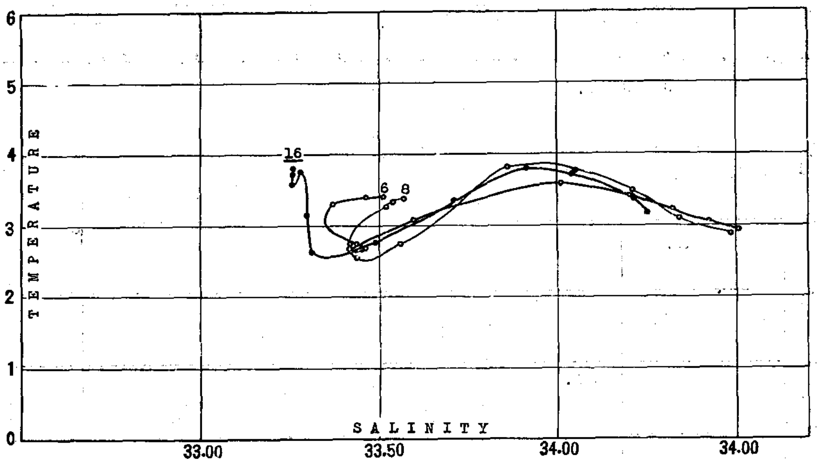

Fig. 22. T–S relations at stations to the east of the Bowers Bank in the Bering

surface salinity as well as surface temperature generally increases towards the east except at station 19 where the surface salinity is below 33.2 ‰ (fig. 23); at station 20 a homogeneous surface layer of 33.39 ‰ in salinity is met with in the 1954 cruise (fig. 24). The deep water at stations 20 and 21 is distinctly higher in salinity than at other stations in the Bering (fig. 24); therefore, it can not be considered to have come from the Pacific through any of the shallow channels between the Aleutian Islands though it is very similar in character to the Subarctic Water. Sverdrup *et al.* (1942) have shown that the temperature and salinity structures of the Bering basin below 100 m are very similar to those in the Subarctic region of the North Pacific. The character of the water in the deep portions of the Bering is shown in figure 24, using the materials obtained at *Dalinevastochinik*-station 68 (58-59 N, 174-24 E) in her cruise of September 1932 and *Komahashi*-station 67 (57-20 N, 176-26 E) in her cruise of August 1936. The deep

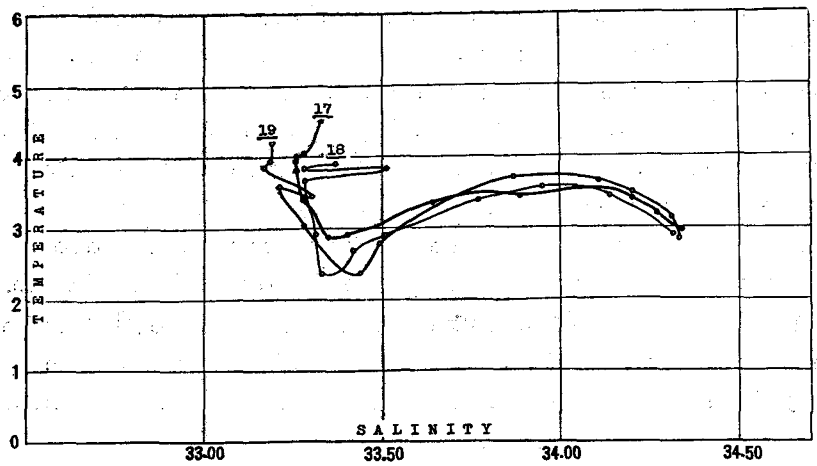

Fig. 23. T-S relations at stations to the west of the Bowers Bank in the Bering

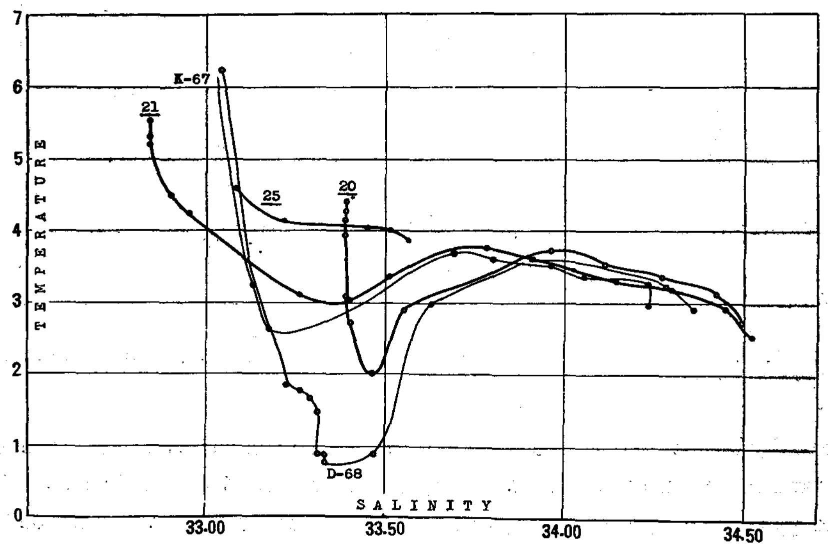

Fig. 24. T-S diagrams at stations off the continental shelf of Bristol Bay in the Bering. T-S relations of the Bering basin water at *Komahashi*-station 67 in August 1936 and *Dalinevastochinik*-station 68 in September 1932 are also shown. Locations of stations are shown in figure 1.

water at stations 20 and 21 is similar to that of the Bering basin but is still slightly higher in salinity. In this area, an accumulation of more dense water than in the adjacent area has been met with as ascertained by several data obtained in the previous cruises of *Komahashi* and *Chelan*. The T-S relations below 100 m level for

Komahashi-stations D (53-54 N, 172-38 W) and F (55-50 N, 176-10 W) in her cruise of August 1934 and for *Chelan*-stations 106 (54-22 N, 168-17 W) and 107 (55-04 N, 168-49 W) in her cruise of August 1933, are similar to that for stations 20 and 21; furthermore, these waters are more dense than the surrounding water as characterized by T-S diagrams for *Komahashi*-stations C (53-29 N, 175-26 W) and E (56-14 N, 171040 W) and for *Chelan*-station 102 (53-57 N, 167-52 W) (fig. 25). This accumulation of dense water

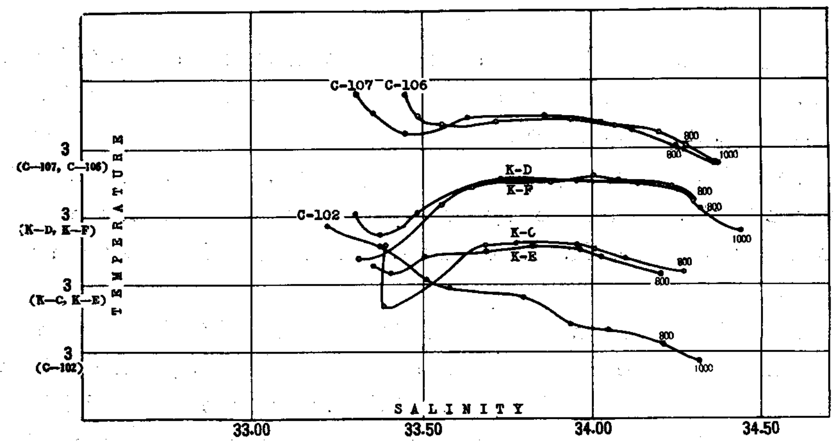

Fig. 25. T-S diagrams below 100 m at a number of *Komahashi* and *Chelan*-stations to the east of the Bowers Bank. Locations of stations are shown in figure 1.

suggests the occurence of a large counter-clockwise eddy as discussed below, and the high salinity of the deep water in this area is probably due to the upwelling of the deeper water caused by the eddy motion.

The water at station 19 is considered to belong to the Bering basin water especially for its low surface salinity, while the remarkably high salinity of the shallow layers at station 20 is considered to be of Pacific origin. The surfacce layer of the Subarctictic Water which has high salinity above 33.5 ‰ is probably carried from the Pacific into the Bering probably through the channel between Attu and the Komandorskie Islands and then flows east along the northern side of the Aleutian Islands. The T-S curves at stations 6 and 8 of the 1953 cruise and at stations 16, 17, 18 and 19 of the 1954 cruise show complicated and irregular fluctuations of salinity value in shallow layers for each station (fig. 23), which may indicate the advance of mixing process of the Subarctic Water with the water of the Bering basin or with the water which has come from the Gulf of Alaska and entered into the Bering through some of the channels between the Aleutian Islands. The water at station 25 is high in salinity and is considered to belong to the same water as that at station 20 (fig. 24). The inflow of the Subarctic Water of the North Pacific into the Bering, however, can not be found in the present observations; probably it is of intermittent character because the surface water at

Chelan-stations 106 and 107 and *Komahashi*-stations D and F never shows higher salinity than 33.0 ‰ in the respective year.

The surface salinity decreases from station 21 eastward to Bristol Bay where the values are below 32 ‰, indicating that the runoff from the large Alaskan rivers stretches far west to station 21.

V. Current

Something has been said about the prominent features of the currents in the present regions. A discussion follows on the currents based on the charts showing the topography and profiles of the isobaric surfaces.

In figure 26 is shown the dynamic topography of the isobaric surfaces 100-decibar relative to the 750-decibar surface by means of the data obtained on the 1953 cruise. When preparing this figure, the courses of the isotherms and isohalines are taken into consideration.

The northern branch of the Kuroshiwo Extension is found to flow northeast to the south of station 2. To the north of latitude 50° north, a westerly current carries warm water of low salinity which is slightly deflected south to the south of Kiska Island, swings north at about longitude 170° east, and then returns to the east to the south of Attu Island, forming thus a large clockwise eddy with its center at station 21. It is then swung north and the major part of that mass of water passes through the channel between Attu and Kiska Islands into the Bering, while the minor part seems to pass over the ridge to the west of Attu Island.

Between the Aleutian Current and this westerly current in the Pacific, a narrow belt of low temperature stretches from west to east which can be traced as far as longitude 170° west as mentioned above.

In the Bering Sea, the water from the Pacific moves towards the east along the Aleutian Islands but is soon deflected towards the Islands partly on account of the thrusting out of the cold water of the Bering basin at station 8 and partly following the bottom contours of the Bowers Bank. It turns again to the east and then to the northeast passing between stations 5 and 6, and flows into the western Hemisphere.

The profiles of the isobaric surfaces in Section I are represented in figure 27. The westerly current in the Pacific shows a velocity which, at the surface, is 4 cm/sec between stations 3 and 4, decreases with increasing depth, until at 500 m level the westward velocity is below 0.5 cm/sec. The easterly current between stations 2 and 3 has a velocity of 3 cm/sec at the surface and at 200 m level it practically disappears. The westerly current in the Gulf of Alaska was calculated 7 cm/sec at the surface (Sverdrup, 1944) with reference to 2000-decibar surface, but the current value obtained on the *Komahashi* cruise in 1935 by the current meters in two layers (10 m and 500 m) was 0.3 knot to the

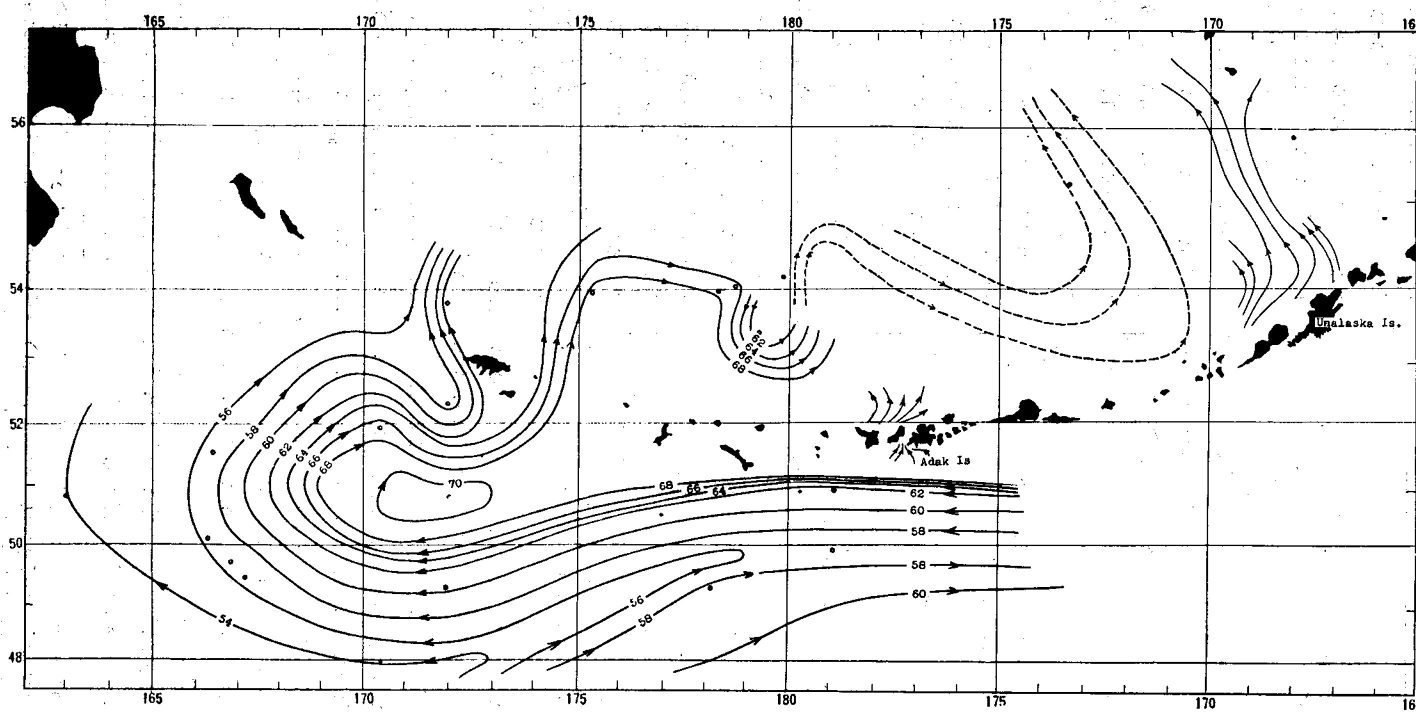

Fig. 26. Geopotential topography of the 100-decibar surface in dynamic centimeters referred to the 750-decibar surface according to the observation on May 14 to June 6, 1953

The broken lines show schematically the currents in the area to the east of the Bowers Bank in the Bering according to the observation on May 26 to June 8, 1954. Near Adak Island and to the north of Unalaska Island, directions of flow are shown schematically according to the observations on *Gannet* in June 1933 and *Chelan* in August 1934 (Barnes & Thompson, 1938).

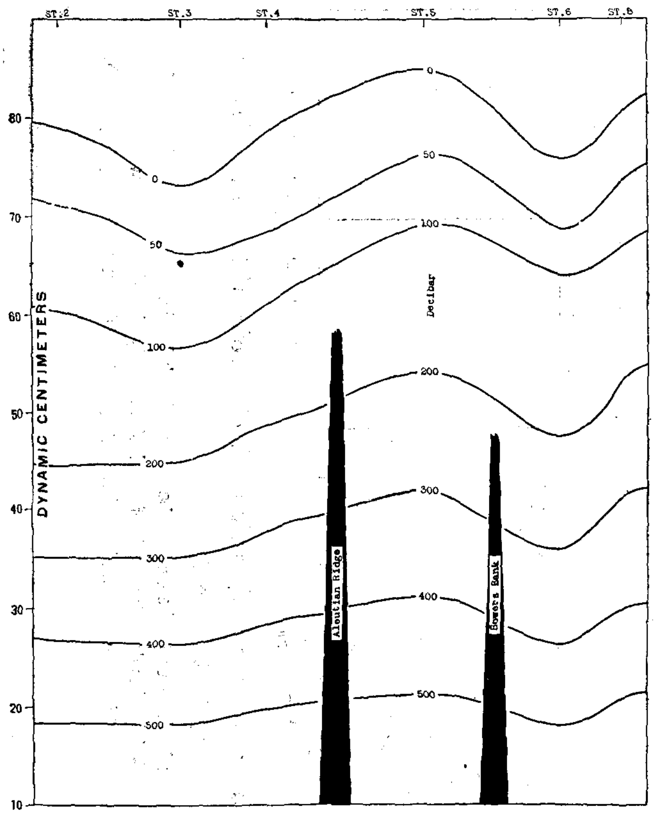

Fig. 27. Profiles of isobaric surfaces in dynamic centimeters referred to the 750-decibar surface in Section I on May 15 to 18, 1953

south of the Aleutian Islands in longitude 180°. The velocities of this westerly current shown in the "Current Chart of the North Pacific" vary from 0.3 to 0.5 knot. These values are higher than are found on the present observations suggesting that the prevailing winds exert some effect on the surface layers as well as that the water at a depth of 750 m is not at rest as supposed in the present writers' computation.*

Between stations 5 and 6, is found a northerly current which has velocities of 5 cm/sec at the surface and of 2 cm/sec at 500 m level. Between stations 6 and 8, the Bering basin water thrusts out, the velocity of which is 6 cm/sec at the surface and increases slightly with increasing depth reaching 8 cm/sec at 200 m level. Below this level, the velocities decrease with increasing depth until at 500 m level the value is 3 cm/sec.

The profiles of the isobaric surfaces in Section II are represented in figure 28. The westerly current between stations 20 and 21 is a little more accelerated than in Section I and the velocity which, at the surface, is 6 cm/sec, decreases with increasing depth especially rapidly below 200 m. The returning flow between stations 21 and 13 has a higher velocity of 7 cm/sec at the surface which also decreases but slightly with depth down to a level of 100 m; below this level it decreases rapidly. At 500 m level the waters are practically motionless.

In figure 29 is represented the profiles of the isobaric surfaces with reference to 800-decibar level in the whole section of the 1954 cruise. The broken lines in the figure

* Taguchi & Hirose (1954) have measured a high velocity of about 2 knots to the south of Kiska Island in May 1953 by current meters in two layers (10 m and 500 m) in the boundary area between the water of low transparency to the north and the water of high transparency to the south.

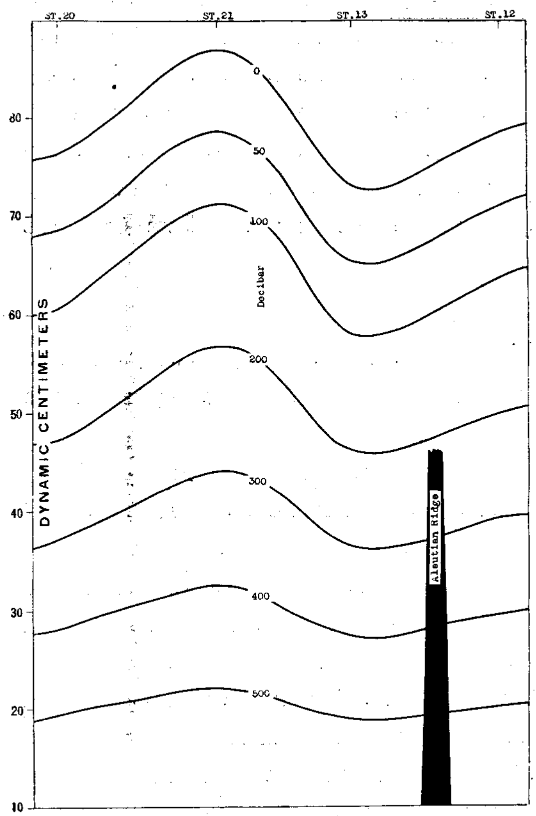

Fig. 28. Profiles of isobaric surfaces in dynamic centimeters referred to the 750-decibar surface in Section II on May 20 to June 6, 1953

indicate the axises of no motion normal to the section. In the central part of the section, the general features of currents are prctically identical to those in the preceding year. The current which enters the Bering from the Pacific between stations 13 and 14 has a velocity of 4 cm/sec at the surface which is of the same order as found between stations 3 and 4 in 1953. At station 16, in the Bering, a thrusting out of the Bering basin water towards the south is met with in this year also, but in a more weak current than in the preceding year. Between stations 7 and 10, is found a slight horizontal undulation of the currents which probably indicates a minor development of eddy motion on the boundary between the warm water from the Gulf of Alaska and the cold water from the Bering.

In the southwestern part of the section, there is found a remarkable horizontal undulation of the water passing in and out of the vertical plane of the section, indicating the development of successive whirls between the cold water from the Okhotsk and the warm water of the Kuroshiwo Extension. The current velocity, however, does not exceed 3 cm/sec at the surface and decreases with increasing depth.

To the east of the Bowers Bank in the Bering the flows of water are generally slow except in the easternmost region to the east of station 20 where is found a northward current of high velocity of 8 cm/sec at the surface. Between stations 17 and 20, the southerly inflow of the Bering basin water is found, while to the west of station 17 there is a northerly current. The water of the latter current is considered to be composed mainly of the waters from the Pacific; one part may come through the channels of the Aleutian Islands to the west of longitude 180° and flows east and then northeast between stations 5 and 6 of the 1953 cruise, and the other part may come through the Tanaga or Amchitka Passes and flow northward (Barnes & Thompson, 1938).

Thus, there are found two successive eddies to the west of the Bowers Bank. One of them rotates clockwise with its center in the vicinity of station 17 at the surface. The same eddy was found in the USS Nereus cruise in the summer of 1947 (LaFond & Pritchard, 1952). The axis of rotation of this eddy seems to be extremely oblique especially below 300 m level as seen in the figure; at the surface it lies at station 17, while at a depth of 600 m it lies at station 19. The other is a counter-clockwise circulation of water with its center at station 20, the axis of which seems also to be slightly oblique. In figure 26 the currents of the regions to the east of the Bowers Bank are shown schematically.

VI. Summary

1. The hydrographic work performed on two cruises made during the early summers of 1953 and 1954 to the vicinity of the Aleutian Islands and the southern part of the Bering Sea has been outlined.

2. Along the southern side of the Aleutian Islands, a warm water mass of low salinity is found to flow from east to west. It reaches as far west as longitude 165° east, on its way spreading several branches into the Bering through the shallow channels between the Aleutian Islands, then it swings north or northeast into the Bering from the Pacific passing over the Aleutian Ridge near Attu Island. A large clockwise eddy of this warm water is, thus, formed to the south or southwest of Attu Island.

3. Between this warm water and the Kuroshiwo Extension or Aleutian Current an abnormally cold water of low salinity is found to flow westward, forming a very narrow tongue. It originates principally from the Bering, probably from the Gulf of Anadir, and then moves along the eastern coast of Kamtchatka. It is then deflected east or northeast off the Kurile Islands and flows east along the Aleutian Islands in latitude 50° north.

4. Off the southern islands of the Kuriles, another cold water of low salinity is found which originates from the Okhotsk Sea as distinguished from the water of Bering origin by the lower temperature of deep water below 100 m level.

5. In the Bering Sea, waters from the Pacific set east just to the north of the Aleutian Islands. The salinities of the southern Bering are of lower values than in the Pacific indicating the occurrence of a downward transport of the shallow water which has poured into the Bering form the Pacific.

6. The Bering basin water thrusts south or southeast especially to the east of the Bowers Bank, while the fresh water of Bristol Bay moves north. Thus, two successive whirls; one clockwise and another counter-clockwise, develop to the east of the Bowers Bank.

7. Stratification of water consisting of an upper layer of relatively cold water of low salinity resting on a warm and saline water, is found at most of the stations. The most conspicuous features of stratification are the existence of a subsurface layer of cold water of low salinity at about 100 m depth and an intermediate layer of maximum

Figure 29. Profiles of isobaric surfaces in dynamic centimeters referred to the 800 decibar surface in the whole section covered on May 26 to June 8 by the 1954 cruise Broken lines show the axises of no motion normal to the section.

temperature at about 300 m depth. The cause of such stratification in these regions is mainly the advection of the severely cold and fresh water from the Asiatic coast of the Bering Sea spreading over waters of greater density from the Pacific.

8. The current velocities calculated from the inclinations of isobaric surfaces are below 10 cm/sec everywhere; they are in most cases greatest at the surface.

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Appendix

Observations obtained on the cruise of the "*Oshoro Maru*" in 1953

Station	1		2		3		4		5	
Lat. Long.	49. 22 N 178. 18 E		48. 57 N 178. 49 W		50. 00 N 178. 44 W		50. 58 N 178. 40 W		52. 36 N 178. 46 W	
Date	V — 14		V — 15		V — 15		V — 16		V — 17	
Time	20.00— 1.15		13.45—16.15		23.40— 2.00		8.35—10.25		1.20— 3.00	
	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
0	4.25	33.22	4.90	33.26	4.58	33.20	5.68	32.81	4.76	33.24
10	4.23	33.19	4.59	33.01	4.22	33.05	5.39	32.74	4.64	33.15
25	3.50	33.10	4.14	33.26	3.43	32.97	4.57	32.74	4.15	33.21
50	3.30		3.59	33.25	3.21	33.26	3.20	33.24	3.76	33.35
75	3.24	33.17	3.40	33.24	3.16	33.26	3.14	33.39	3.66	33.42
100	3.14	33.24	3.24	33.29	2.92	33.28	3.06	33.40	3.66	33.42
150	3.73	33.91	3.79	33.69	3.95	33.91	4.05	33.80	3.23	33.19
200	3.77	34.02	3.84	34.04	3.87	34.05	4.11	33.95	3.25	33.63
300	3.74	34.17	3.85	34.14	3.72	34.23	3.66	34.09	3.35	33.87
400	3.58	34.26	3.71	34.27	3.50	34.28	3.57	34.20	3.50	34.01
500	3.44	34.32	3.44	34.31	3.40	34.35	3.54	34.27	3.55	34.15
750	2.94	34.40	3.08	34.49	2.98	34.41	3.12	34.43	3.12	34.37
1000	2.63	34.59	2.74	34.51	2.83	34.53	2.84	34.52	2.87	34.48

Station	6		8		10		11		12	
Lat. Long.	53. 22 N 179. 27 E		54. 00 N 178. 57 E		53. 50 N 175. 24 E		53. 35 N 173. 43 E		53. 42 N 172. 09 E	
Date	V — 17		V — 18		V — 19		V — 19		V — 20	
Time	13.20—14.45		7.30— 8.30		9.30—10.30		19.20—20.50		5.20— 7.00	
	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
0	3.40	33.51	3.38	33.57	3.44	33.55	2.58	33.33	3.19	33.30
10	3.38	33.46	3.35	33.54	3.43	33.40	2.95	33.28	3.17	33.30
25	3.30	33.37	3.27	33.52	3.25	33.08	2.94	33.26	3.13	33.30
50	2.82		2.74	33.42	2.93	33.22	2.92	33.28	3.03	33.30
75	2.75	33.43	2.69				2.75	33.24	2.74	33.31
100	2.70	33.47	2.55	33.44			2.64	33.24	2.51	33.30
150	2.69	33.42	2.73	33.56			3.18	33.66	3.08	33.53
200	3.08	33.60	3.00	33.70			3.91	33.82	3.78	33.87
300	3.58	34.01	3.86	33.86			3.62	33.98	3.64	34.08
400	3.38	34.21	3.56	34.05			3.52	34.13	3.52	34.14
500	3.21	34.32	3.50	34.21			3.42	34.27	3.50	34.20
750	3.00	34.46	3.10	34.34			3.25	34.37	3.13	34.46
1000	2.86	34.52	2.90	34.50					2.92	34.49

Station	13		14		15		16		17	
Lat. Long.	52. 15 N 172. 07 E		49. 55 N 160. 15 E		49. 33 N 167. 01 E		50. 09 N 166. 14 E		51. 28 N 166. 24 E	
Date	V — 20		V — 21		V — 24		V — 25		V — 27	
Time	19.10—21.00		17.30—18.30		13.00—14.10		16.00—18.00		14.30—16.00	
	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-peraturs	Salinity	Tem-perarure	Salinity
0	3.20	33.55	4.30	33.31	3.60	33.30	4.35	33.15	4.28	33.30
10	3.13	33.30	3.59	33.26	3.59	33.28	3.58	33.30	4.27	33.30
25	3.04	33.30	3.49	33.26	3.42	33.31	3.01	33.28	3.78	33.26
50	3.10	33.30	3.29	33.28	2.13	32.83	2.10	33.30	2.79	33.23
75	2.60	33.26	2.92	33.21	1.46	33.30	1.98	33.22	2.57	33.26
100	2.56	33.34	2.82	33.30	1.50	33.06	1.92	33.26	2.33	33.26
150	3.25	33.88	2.94	33.48	3.13	33.77			2.55	33.72
200	3.04	33.90	3.82	33.87	3.30	34.02			3.23	33.96
300	3.48	34.15	3.82	34.02	3.35	34.19			3.38	34.21
400	3.48	34.24	3.64	34.12	3.29	34.28			3.45	34.26
500	3.51	34.31	3.55	34.18	3.17	34.33			3.45	34.34
750	3.05	34.45	3.19	34.33	2.75	34.42			2.78	34.48
1000	2.50	34.50	2.75	34.40						

Station	18		19		20		21	
Lat. Long.	50. 55 N 161. 23 E		49. 50 N 166. 46 E		49. 24 N 172. 00 E		50. 51 N 172. 00 E	
Date	VI — 1		VI — 2		VI — 5		VI — 6	
Time	8.00—10.00		20.00—22.00		13.00—15.30		12.00—14.00	
	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity
0	2.96	33.42	3.50		3.55	33.31	3.90	33.30
10	2.95	33.35	3.48	33.37	3.36	33.22	3.72	33.08
25	2.85	33.21	3.45	33.31	3.28	33.21	3.84	33.24
50	0.75	33.26	1.66	33.33	3.20	33.35	3.45	33.28
75	0.38	33.21	1.26	33.30	3.15	33.21	3.46	33.26
100	0.01	33.35	1.06	33.35	2.30	33.15	2.76	33.26
150	2.88	33.89	1.60	33.50	2.18	33.42	3.62	33.40
200	3.34	34.04	3.44	33.99	3.01	33.89	3.60	33.70
300	3.42	34.16	3.41	34.17	3.49	34.13	3.94	33.83
400	3.34	34.27	3.30	34.24	3.46	34.20	3.84	33.93
500	3.13	34.31	3.13	34.29	3.30	34.26	3.73	34.13
750	2.76	34.44	2.45	34.46	2.94	34.40	3.11	34.29
1000	2.72	34.53			3.08	34.52	2.86	34.34

Observations obtained on the cruise of the "*Oshoro Maru*" in 1954

Station	1		2		3		4		5	
Lat. Long.	42. 15 N 145. 41 E		42. 43 N 147. 21 E		43. 23 N 148. 51 E		44. 12 N 150. 38 E		45. 04 N 152. 23 E	
Date	V — 26		V — 27		V — 27		V — 28		V — 28	
Time	17.20—18.50		05.00—06.30		7.00—18.08		5.00— 6.00		7.00—18.15	
	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity
0	4.8	33.14	3.4	33.17	2.4	33.19	2.5	33.15	2.6	33.21
10	4.84	33.15	3.35	33.15	2.27	33.17	2.30	33.17	2.28	33.17
25	3.78	33.30	2.46	33.21	2.02	33.17	2.34	33.15	2.02	33.17
50	3.26	33.30	1.79	33.21	1.79	33.18	1.66	33.21	1.82	33.21
75	2.36	33.30	1.35	33.26	1.17	33.22	1.22	33.22	1.14	33.22
100	1.91	33.25	1.13	33.26	0.86	33.28	1.06	33.22	1.46	33.38
150	0.74	33.39	0.80	33.43	1.45	33.49	1.01	33.44	1.18	33.57
200	1.41	33.52	1.10	33.49	2.19	33.76	2.07	33.65	1.79	33.76
300	2.46	33.78	1.71	33.68	2.71	33.94	2.96	33.94	2.54	33.85
400	2.88	33.91	2.96	33.97	2.77	34.08	3.13	34.12	2.92	34.00
600	2.99	34.14	2.97	34.23	2.89	34.28	2.90	34.28	2.94	34.24
800	2.80	34.33	2.83	34.38	2.65	34.38	2.65	34.45	2.80	34.37
1000	2.68	34.33	2.68	34.45	2.58	34.46	2.41	34.47	2.52	34.59

Station	6		7		8		9		10	
Lat. Long.	45. 59 N 154. 16 E		46. 52 N 156. 02 E		47. 49 N 157. 59 E		48. 39 N 160. 07 E		49. 25 N 162. 12 E	
Date	V — 29		V — 29		V — 30		V — 30		V — 31	
Time	5.00— 6.05		17.00—18.00		15.00— 6.58		16.40—17.40		4.05— 5.00	
	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity
0	2.0	33.33	1.6	33.21	1.7	33.28	1.5	33.30	1.8	33.30
10	1.89	33.44	1.41	33.21	1.59	33.24	1.41	33.22	1.79	33.48
25	1.87	33.30	1.36	33.21	1.64	33.24	1.45	33.24	1.78	33.22
50	1.65	33.30	1.28	33.21	1.49	33.26	1.38	33.24	1.66	33.24
75	1.57	33.30	1.17	33.21	1.20	33.30	1.31	33.26	0.84	33.26
100	1.17	33.46	0.74	33.22	1.02	33.27	1.06	33.24	0.75	33.37
150	0.64	33.36	1.15	33.44	2.73	33.86	2.14	33.70	2.28	33.58
200	0.83	33.38	2.64	33.77	3.44	34.03	3.15	33.95	3.37	33.89
300	2.05	33.74	3.30	34.07	3.45	34.15	3.48	34.13	3.48	34.13
400	2.38	33.81	3.15	34.16	3.32	34.26	3.32	34.20	3.33	34.25
600	2.77	34.09	2.99	34.34	3.03	34.36	3.00	34.33	3.09	34.36
800	2.87	34.27	2.85	34.46	2.80	34.60	2.80	34.44	2.85	34.43
1000	2.60	34.69	2.71	34.47	2.47	34.69	2.54	34.48	2.58	34.51

Station	11		12		13		14		15	
Lat. Long.	50. 15 N 164. 28 E		51. 03 N 166. 43 E		51. 44 N 168. 43 E		52. 34 N 171. 04 E		53. 14 N 173. 28 E	
Date	V — 31		VI — 1		VI — 1		VI — 2		VI — 2	
Time	16.00—16.55		4.00— 5.00		16.05—17.00		4.00— 4.55		16.00—16.53	
	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
0	3.3	33.33	2.8	33.26	3.1	33.26	4.2	33.10	4.3	33.13
10	3.17	33.28	2.64	33.26	2.63	33.26	4.12	33.08	3.89	33.12
25	2.97	33.28	2.60	33.24	2.52	33.26	3.95	33.08	3.78	33.15
50	2.82	33.28	2.36	33.26	2.46	33.26	3.85	33.08	3.36	33.13
75	2.34	33.30	2.26	33.24	2.18	33.26	3.34	33.15	3.36	33.17
100	1.98	33.32	2.05	33.35	1.84	33.26	3.01	33.26	2.99	33.26
150	2.22	33.48	2.99	33.68	2.83	33.78	2.66	33.36	3.00	33.15
200	3.54	33.78	3.35	33.97	3.45	34.00	3.72	33.69	3.40	33.46
300	3.82	34.02	3.64	34.07	3.45	34.11	3.95	34.13	3.94	33.84
400	3.64	34.12	3.45	34.15	3.35	34.20	3.83	34.05	3.84	33.98
600	3.41	34.24	3.19	34.26	3.10	34.31	3.58	34.20	3.54	34.16
800	3.07	34.33	2.90	34.38	2.87	34.38	3.31	34.27	3.23	34.25
1000	2.75	34.40	2.70	34.42	2.57	34.43	2.96	34.34	3.11	34.36

Station	16		17		18		19		20	
Lat. Long.	53. 59 N 178. 13 E		54. 19 N 179. 59 E		54. 38 N 177. 54 W		54. 51 N 175. 40 W		55. 06 N 173. 09 W	
Date	VI — 5		VI — 6		VI — 6		VI — 6		VI — 7	
Time	3.00— 4.05		15.00—15.55		3.05— 3.57		15.05—16.10		3.04— 3.55	
	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
0	3.8	33.26	4.5	33.33	3.9	33.37	4.2	33.19	4.4	33.39
10	3.57	33.26	4.04	33.28	3.69	33.28	3.95	33.19	4.27	33.39
25	3.73	33.26	4.01	33.26	3.84	33.51	3.86	33.17	4.15	33.39
50	3.76	33.28	3.96	33.26	3.74	33.28	3.45	33.30	3.94	33.39
75	3.15	33.30	3.82	33.26	2.92	33.31	3.62	33.21	3.08	33.39
100	2.64	33.31	3.42	33.28	2.36	33.33	3.05	33.28	2.71	33.40
150	2.77	33.49	2.88	33.35	2.68	33.42	2.38	33.44	2.00	33.46
200	3.35	33.71	2.91	33.40	2.90	33.51	2.80	33.49	2.88	33.55
300	3.80	33.91	3.36	33.64	3.40	33.77	3.74	33.87	3.71	33.96
400	3.72	34.04	3.45	33.89	3.56	33.95	3.66	34.11	3.51	34.11
600	3.40	34.20	3.38	34.20	3.45	34.16	3.48	34.20	3.38	34.27
800	3.17	34.25	3.18	34.27	3.14	34.25	3.15	34.31	3.13	34.42
1000			2.95	34.34	2.81	34.34	2.83	34.33	2.71	34.49

Station	21		22		23		24		25	
Lat. Long.	55. 25 N 170. 37 W		55. 46 N 167. 58 W		56. 22 N 165. 16 W		54. 43 N 165. 56 W		52. 43 N 171. 24 W	
Date	VI — 7		VI — 8		VI — 8		VI — 15		VI — 16	
Time	15.00—15.53		2.22— 2.37		14.00—14.10		9.00— 9.48		15.05—15.26	
	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity
0	5.3	32.84	5.3	32.36	5.0	31.74	5.2	32.72	4.6	33.08
10	5.53	32.84	5.35	32.36	5.06	31.91	5.33	32.70	4.15	33.21
25	5.21	32.84	5.15	32.36	0.39	31.91	4.22	32.86	4.61	33.42
50	4.25	32.95	3.74	32.45	-0.76	31.96	4.55	32.90	4.03	33.44
75	4.49	32.90	3.48	32.77			4.15	32.95	4.00	33.51
100	3.10	33.26	3.46	32.95			3.98	33.10	3.86	33.55
150	3.01	33.40					3.59	33.21		
200	3.36	33.51					3.70	33.35		
300	3.75	33.78								
400	3.59	33.91								
600	3.30	34.18								
800	2.93	34.45								
1000	2.54	34.52								

Station	26		27		28	
Lat. Long.	51. 10 N 172. 52 W		49. 47 N 176. 11 E		49. 41 N 171. 16 E	
Date	VI — 17		VI — 19		VI — 20	
Time	8.30— 9.25		13.15—14.10		13.00—14.02	
	Tem-perature	Salinity	Tem-perature	Salinity	Tem-perature	Salinity
0	5.2	32.95	4.8	33.13	5.3	22.15
10	5.72	32.95	4.65		5.14	33.15
25	4.55	32.95	4.60	33.12	4.94	33.21
50	4.89	32.95	4.18	33.15	3.95	33.22
75	3.26	33.10	3.43	33.26	2.82	33.22
100	3.10	33.26	3.06	33.42	3.34	33.30
150	3.96	33.77	3.54	33.98	3.65	33.96
200	4.18	34.04	3.80	34.07	3.67	34.05
300	4.06	34.14	3.71	34.18	3.68	34.16
400	3.80	34.22	3.39	34.27	3.57	34.31
600	3.46	34.33	3.14	34.38	3.27	34.42
800	3.18	34.43	2.87	34.49	2.78	34.49
1000	2.75	34.52	2.44	34.56	2.52	34.56