STRUCTURE OF THE WATERS IN THE BERING SEA AND THE ALEUTIAN REGION*

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1. Introduction

The training ship *"Oshoro Maru"* of the Faculty of Fisheries, Hokkaido University has made cruises into the Bering Sea and the Aleutian region for biological and oceanographic investigations combining with the purpose of drilling of cadets in fishery and navigation practice in the summers since 1955. Each investigation was undertaken under the direction of the Research Committee organized in the Faculty.

In the 1955 cruise, the ship roughly covered the Bering Sea in a period from June to July to get general information on the structure of the whole Bering Sea.

In 1956, her cruise during July and August was limited to the east of longitude 175° East under the fishery treaty between the Japanese and Soviet Governments.

The 1957 cruise covered only the vicinity of the Aleutians for the particular purpose of biological investigation in co-operation with the Hokkaido Regional Fisheries Research Laboratory.

The hydrographic data obtained in the 1955 and 1956 cruises are recorded in "Data Record of Oceanographic Observations and Exploratory Fishing No. 1 (Hokkaido Univ.)". This "Data Record" includes the previous data obtained in the cruises before 1955 also.

Of these data the chlorinity values obtained in 1955 seem to be a little higher, containing some irregularities. There may be certainly some unreliabilities in them. The writers later found that the sample bottles made of polyethylene which were used allowed evaporation of water, perhaps through the wall of the bottles, by measuring the variation of the total weights of the bottles containing water for forty days as shown in Fig. 1.

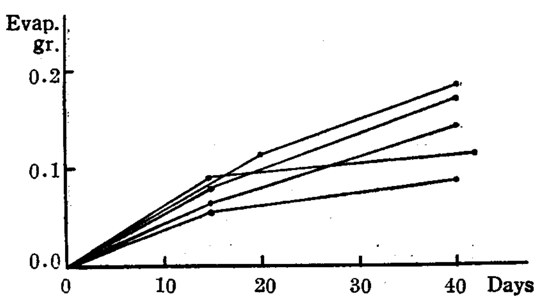

Fig. 1. Evaporation of the sampled water contained in the bottles made of polyethylene. Each sampled water is about 100 c.c..

Many other Japanese vessels, hitherto, have made cruises into the Bering Sea to investigate the hydrography covering more or less partially the western portion of the Bering. Among the most extensive cruises, one made by the *"Komahashi"* in 1936 ranged from May to September; however, the Bering and its vicinity were covered during July to August, the same period as that of the cruise

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of the *"Oshoro Maru"* in 1956. The data obtained in this cruise of the *"Komahashi"* (Marine Safety Agency Tokyo, Japan, 1951), therefore, are very useful to the writers to get information on the general structure of waters in the whole Bering Sea and vicinity by comparison with data gained by the *"Oshoro Maru"* in 1956.

The present studies are mainly based on these data referring to the other data to some extent. The locations of the hydrographic stations occupied by the *"Oshoro Maru"* in 1956 and by the *"Komahashi"* in 1936 are shown together in Fig. 2. The locations of the several other stations which will be referred to are entered in the figure also.

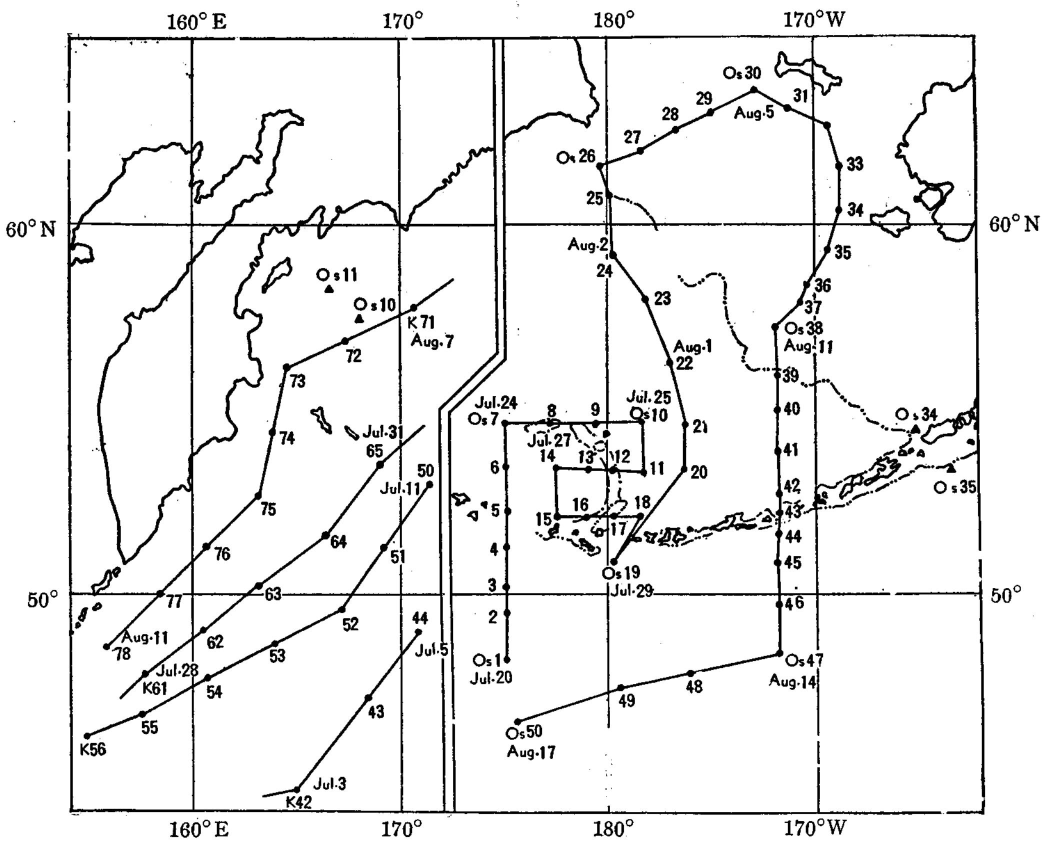


Fig. 2. Locations of the hydrographic stations occupied by the *"Oshoro Maru"* in 1956 and *"Komahashi"* in 1936 and several stations in 1955 cruise of the *"Oshoro Maru"*. Abbreviations: Os, *"Oshoro Maru"* 1956; Os', *"Oshoro Maru"* 1955; K, *"Komahashi"* 1936.

The results of the 1957 cruise (Hokkaido Univ., 1958), of which data are now in press, will be dealt with in another paper being only somewhat referred to here.

2. Currents

The patterns of the currents shown in the two parts of Fig. 3 are drawn, as mentioned previously, on the basis of data obtained by the *"Oshoro Maru"* in 1956 (the right part) and the *"Komahashi"* in 1936 (the left part) respectively.

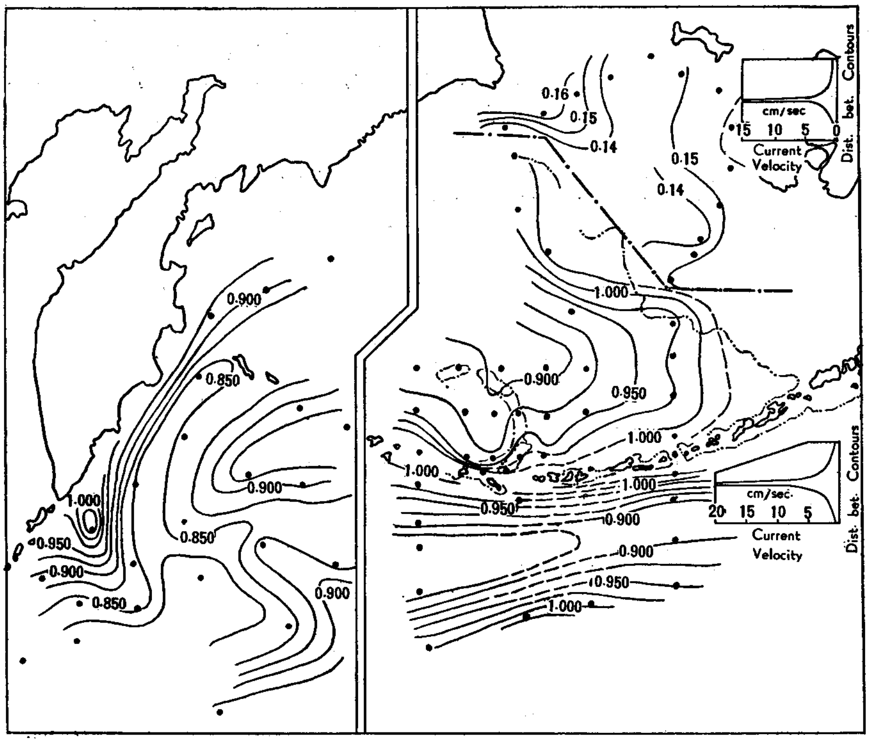


Fig. 3. Geopotential topography of the sea surface relative to the 800-decibar surface. On the shallow continental shelf, geopotential topography of the sea surface relative to the 50-decibar surface is shown.

These two parts of the figure, however, can be considered to represent the parts of an essentially identical condition of the hydrography.

The westerly current along the southern side of the Aleutian Islands, of which part is represented with the broken lines in the right part of the figure, may be regarded as a continuation of the northernmost part of the counterclockwise gyral in the Gulf of Alaska, part of which is a northward branch of the Subarctic Current (Sverdrup *et al.*, 1946). Such a feature of the current along the eastern portion of the Aleutian Islands and in the Gulf of Alaska is apparently seen also in the results of the observations made by *"Therese"* (Pac. Oceanogr. Group, Nanaimo, British Columbia, 1956).

This westerly current stretches as far west as beyond Attu Island toward the Kamchatka Peninsula, though it never reaches there, sending many branches into the Bering Sea through the channels between the Islands. Some details of them have been reported by Barnes and Thompson (1938). Returning to the northeast the major part of the flow enters the Bering Sea close to the west of Attu Island and through the western channels. For this current the name "Alaska Current" will be used through the present studies. The volume transport of this current approximately estimated at the section Sts. Os 42–47 (Fig. 4), for the three layers from the surface to 150 meters, from 150 to 300 meters, and from 300 to 600 meters amount to about 24.8×10^5 m^3/sec, 22.1×10^5 m^3/sec and 25.6×10^5 m^3/sec respectively, while the volume transport at the section Sts. Os 5–1 (Fig. 4) for the

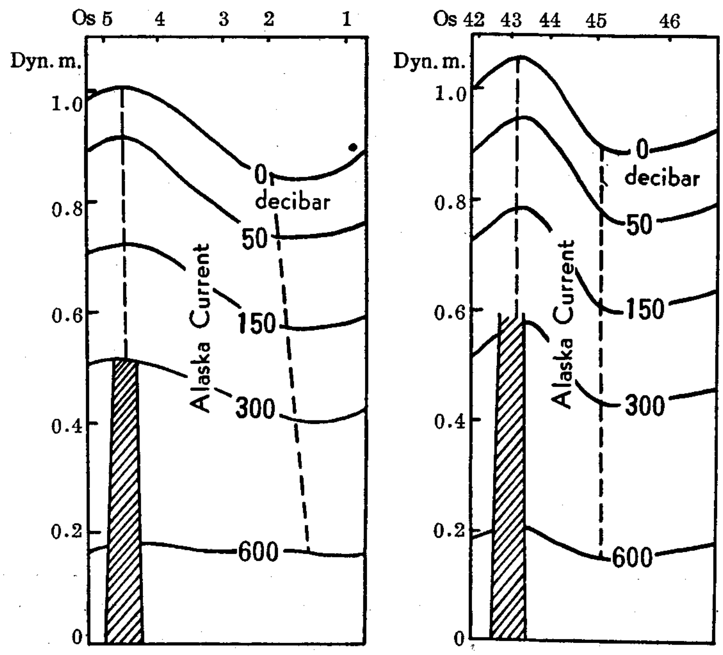


Fig. 4. Profiles of isobaric surfaces in dynamic meters relative to the 800-decibar surface in two sections across the Alaska current.

corresponding layers amount to about 23.2×10^5 m^3/sec, 17.6×10^5 m^3/sec and 17.2×10^5 m^3/sec respectively. Thus the estimation of the volume of water entering the Bering from the Pacific through the channels indicates that it is relatively small at the shallower layers, though such estimation is not necessarily accurate, because, in the western portion, part of the water belonging to another current is added returning on its way. Between these two sections the Pacific water may be allowed to enter in largest volume through the Amchitka Pass because of the great depth of above 1000 meters; the isobaths near St. Os 12 are drawn referring to the isotherms as St. 12 is of a depth shallower than 800 meters.

On the northern side of the Islands, the current, as a whole, moves toward the east or northeast, then swings northwesterly along the bottom contour forming a large counter-clockwise circulation in the Bering Sea.

On the shallow continental shelf off Alaska, in the Bering Sea, the water flows northward, however, part of it perhaps turns toward the southwest since the northward net flow to be allowed to pass through the Bering Strait is rather small (Barnes and Thompson, 1938), then further flows southwestward along the Asiatic coast as seen in the figure, lying over the offshore water. Thus, the major part of the water coming from the Pacific flows out of the Bering along the Kamchatka Peninsula after once have circulated in the Bering Sea. Forming a remarkable clockwise eddy off the southern head of the Kamchatka Peninsula this water further flows southwestward along the Kurile Islands.

Between this current and the western Subarctic Current a counterclockwise gyral seems to be formed over a considerably wide area. For convenience' sake, the name "Western Subarctic Gyral" will be used for this gyral through the present studies. One branch of this gyral extends to the north inrtervening between the western end of the Alaska Current and the southerly current off Kamchatka, another branch extends toward the east between the Alaska Current and the Subarctic Current.

The calculated velocities of the current at the sea surface relative to the 1200-decibar surface are, on the whole, of small values.

The velocity of the Alaska Current, in its eastern portion, is relatively high as much as 17.5 cm/sec, however, in its western portion it is reduced to about 7.5 cm/sec with the increase in width there. Fig. 3 represents the geopotential topography relative to the 800-decibar surface, the limit depth of the "*Komahashi*" observations, so that the calculation results in a little smaller values of velocity, 12cm/sec and 6 cm/sec corresponding to the above noted values respectively.

In the Bering Sea, the current is weak, on the whole, except along the Kamchatka Peninsula, not exceeding 10 cm/sec even at the region of relatively high velocity. Only along the coast of Kamchatka, however, does the velocity probably increase because the width of the current is submitted to a narrowing there; the velocity rises up to 20 cm/sec between Sts. K76 and K77.

In the Bering basin, the difference of the calculated velocities at the sea surface between those referred to the different reference levels above mentioned is only 1 to 2 cm/sec, suggesting the weakness of the current at deeper layers.

Such velocity of the current, in general, does not vary greatly within the upper layer of 100 meters or so from the surface; below this depth it decreases gradually until it becomes about a half that of the surface velocity at a depth of 300 meters (Fig. 5). However, the characteristic feature of this circulation can be seen even down to the 1000-meter level also in the case of the "*Oshoro Maru*" observations.

In the figures, the isobaths of the Alaska Current are drawn supposedly to be monotonous, however, the current is revealed to be more complicated in more precise observation such as that of the "*Oshoro Maru*" in 1957. As seen in Fig. 6 a remarkable eddy is formed between the Alaska Current and the Subarctic Current. And there, the Alaska

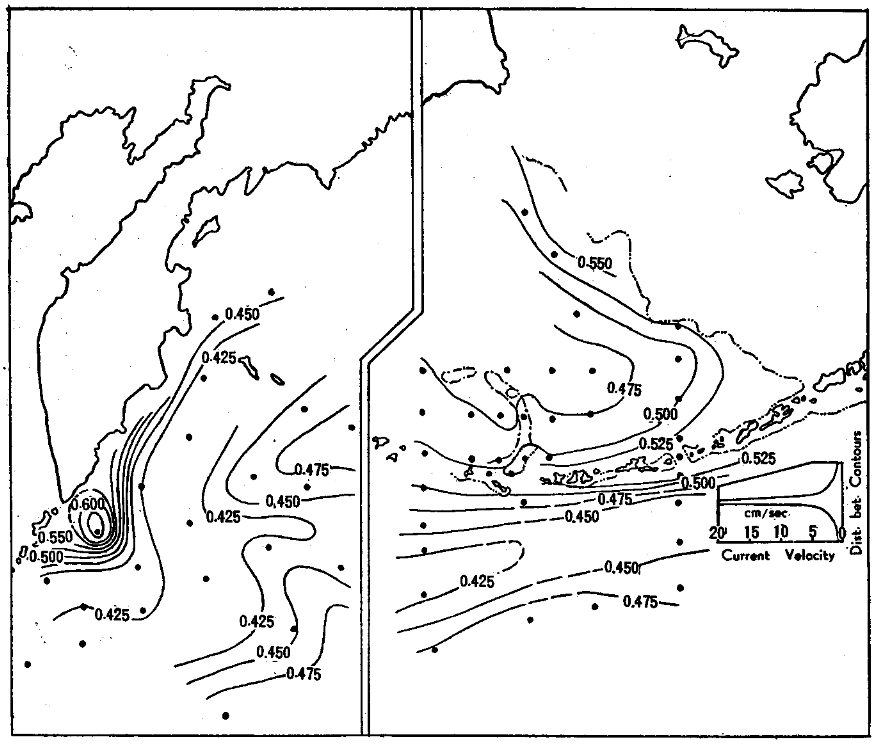


Fig. 5 Geopotential topography of the 300-decibar surface relative to the 800-decibar surface.

Current seems to be extremely narrowed. Referring to the temperature and chlorinity, the water in this eddy is of the same character as that of the Alaska Current. Therefore

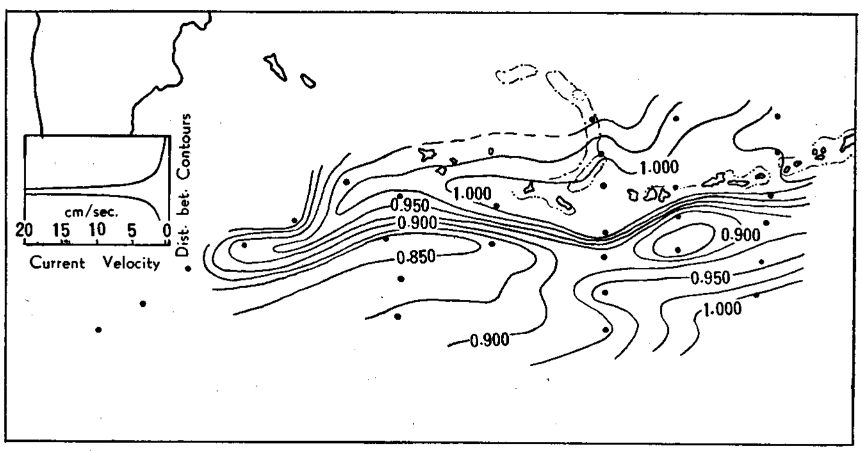


Fig. 6. Geopotential topography of the sea surface relative to the 800-decibar surface according to observations of the *"Oshoro Maru"* in the Aleutian region on June 19 to July 11, 1957.

such an eddy is supposed to have been separated from the main current after it had once protruded like a tongue toward the south and then to take counterclockwise circulation between the two opposite moving currents.

3. Water Masses and their Distribution

It has been stated by Sverdrup (1946) that the Alaska Current, in the Gulf of Alaska, has the character of a warm current in spite of the fact that it carries the water of the Subarctic Current since it comes from the south along the American west coast. The water of the Alaska Current, after entering the Bering, is severely cooled and transformed in winter, and then heated from the surface by radiation in summer circulating there. In the Western Subarctic Gyral, however, the water may be of more complicated character in consideration of the course of its flowing.

Representing the chracteristics of all the waters in the Bering Sea and the vicinity of the Aleutian Islands, the T-Cl relations for all of the stations shown in Fig. 2, except those in the boundary regions of the water masses, are plotted in Fig. 7.

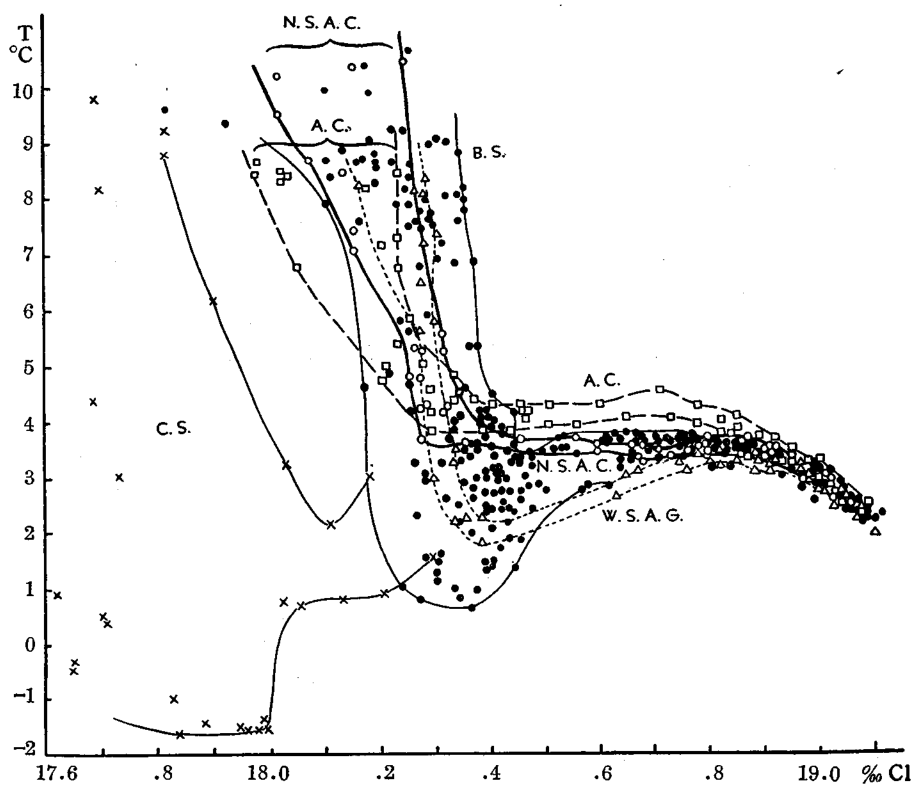


Fig. 7. Temperature-chlorinity relations for all stations shown in Fig. 2 except those in the boundary regions of water masses in the Bering Sea and the Aleutian region. Abbreviations: A. C., Alaska Current; B. S., Bering Sea; C. S., Continental shelf in the Bering; W. S. A. G., Western Subarctic Gyral; N. S. A. C., Northern portion of the Subarctic Current.

A general conspicuous feature of the stratification of the water in these regions is the presence of a minimum temperature layer which is called the Dichothermal layer, and the layer of a maximum temperature underlying it. Toward the deeper layers such as below 800 meters the waters become practically uniform everywhere in the regions.

Referring to the shapes of the curves, they may be classified into five groups as shown in the figure with different symbols. The distribution of so classified waters, with reference to Fig. 3, corresponds to the current systems as seen in Fig. 8. The values of the

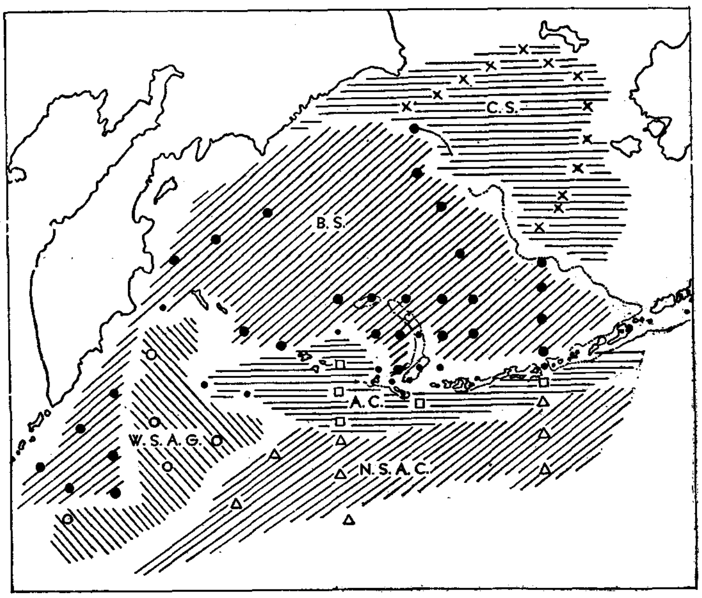


Fig. 8. Areas and boundaries of water masses.

temperature and chlorinity of the dichothermal layer as well as values of the maximum temperature layer show the characteristics proper to the particular waters. Of these waters the following character will be pointed out with reference to Fig. 9 showing the vertical distribution of the temperature and chlorinity of the water. In Figs. 7 and 9 the values for a thin surface layer are not plotted.

a) The water of the Alaska Current.

Except for the surface, the temperature is higher than that of any other waters in these regions through all layers. The dichothermal layer is scarcely found except in the western portion of this current. An indistinct layer of a slight minimum temperature is often found within the depth of 150 to 200 meters, however, it is of very different character as compared with the others found in the Bering Sea and the Western Subarctic Gyral; it lies below the halocline suggesting that it is not the bottom of the convection layer formed in the previous winter, while the other layers lie just above the halocline indicating that they are characteristically themselves.

The chlorinity of the surface layer is as low as less than 18.0‰; from there increasing down to a depth of about 100 meters it reaches to 18.4‰ and below this level, beyond the slight halocline, increasing gradually with the depth it goes up to 19.1‰ at about 1500 meter depth.

b) The water of the Bering Sea.

On the shallow continental shelf off Alaska, where the depth of the sea is not exceeding 100 meters, the water has been severely cooled to below 0°C, and has extremely low chlorinity of 17‰ or so.

In the Bering basin, the dichothermal layer is very distinct; its temperature is 1°C in the northern portion while above 3°C in the southern portion; the depth is about 250 meters in the northern portion while it is 100 meters in the southern portion.

Though thus the temperature of the dichothermal layer ranges 1° to 3°C, the maximum temperature of the lower layer is 3.5° to 3.8°C and never decreases to below 3.4°C even at the lowest. The depth of the layer is about 400 meters in the northern portion, and 300 meters in the southern portion corresponding to the depth of the dichothermal layer.

The upper layer is nearly uniform in chlorinity of 19.3 to 19.4‰. The bottom of it corresponds to the dichothermal layer indicating just the bottom of the convection layer in the winter. Beyond the halocline, the chlorinity increases gradually with the increasing depth.

c) The water in the Western Subarctic Gyral.

From the surface to the dichothermal layer, which lies at a level of 100 meters, the water is uniform in chlorinity of about 18.3‰. The temperature of the dichothermal layer is about 2°C or so being rather higher than the lowest in the Bering, nevertheless the maximum temperature lying at a depth of 300 meters is lower than the lowest in the Bering Sea.

Below the dichothermal layer the chlorinity increases in the same way as in the Bering, however, it seems a little higher than the others down to the deep layer.

d) The water in the northern Subarctic Current.

The water of the Subarctic Current is, as well known, a mixture of the Kuroshio and the Oyashio water. In the northern part of this current, the surface water has been diluted by precipitation in the summer, however, its chlorinity is a little higher than that of the Alaska Current. The convection layer formed in the winter is a little lower in temperature than that of the Alaska Current.

Beneath it, an indistinct layer of minimum temperature appears within the depth of 150 to 300 meters such as is seen in the Alaska Current, however, for all lower layers the temperature is lower than in the Alaska Current, and becomes similar to that in the Western Subarctic Gyral.

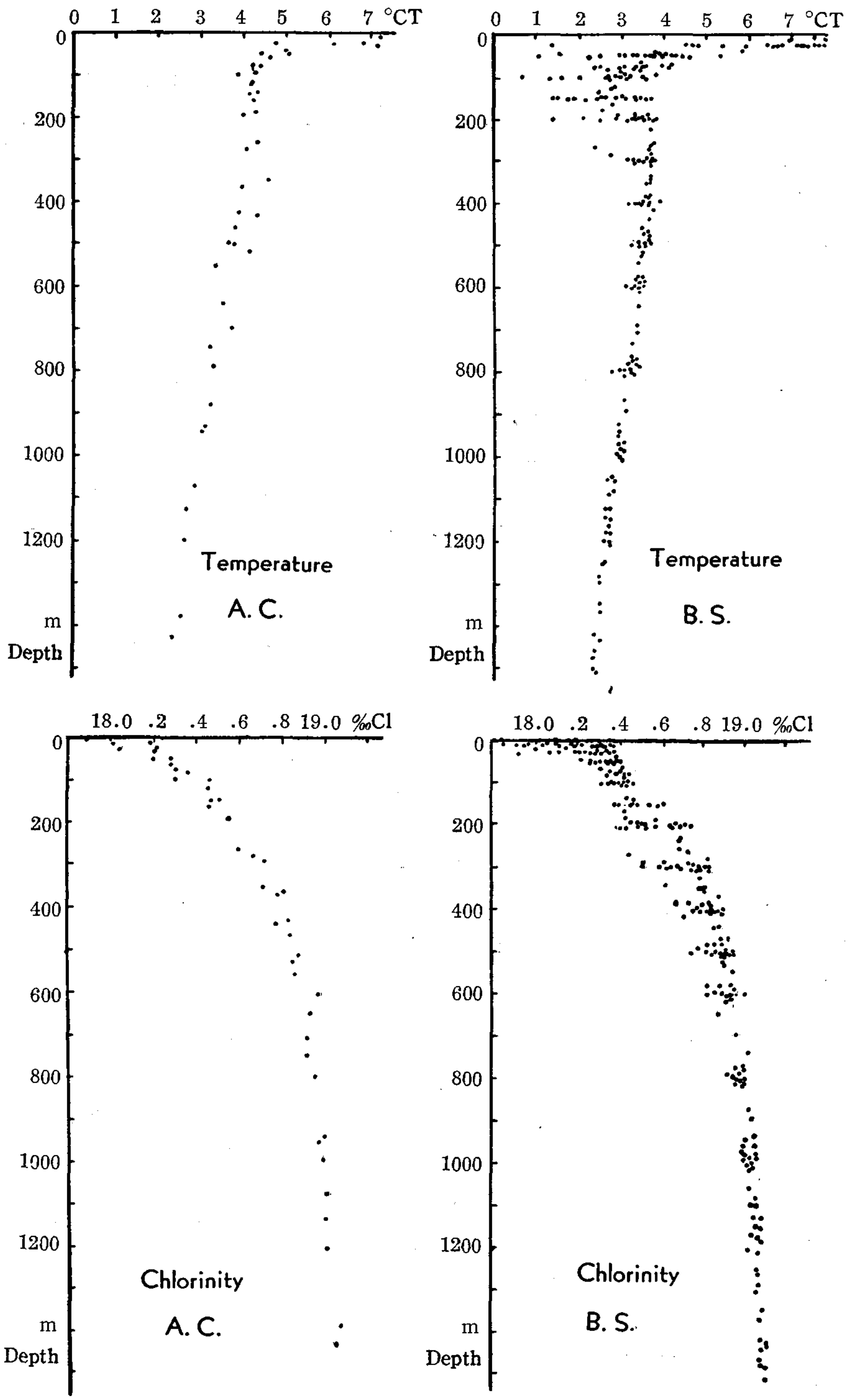
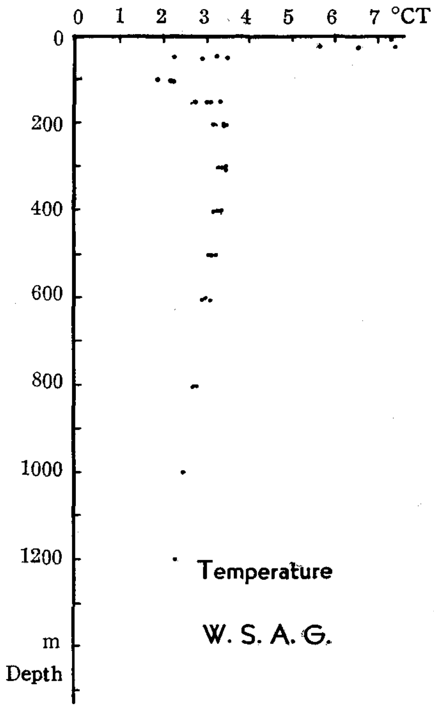


Fig. 9. Vertical distribution of temperature and chlorinity in each area of water masses.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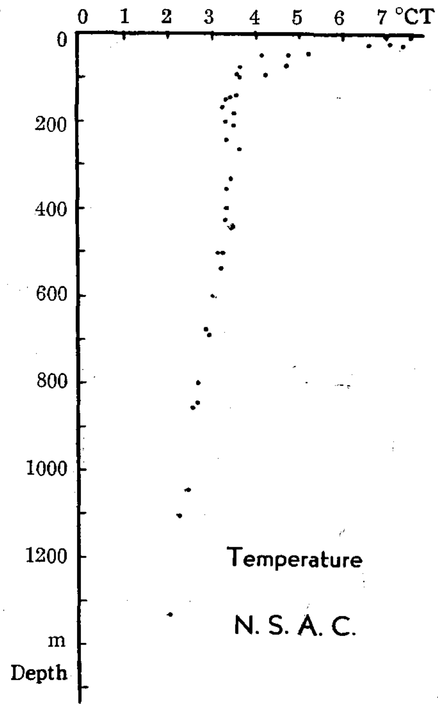
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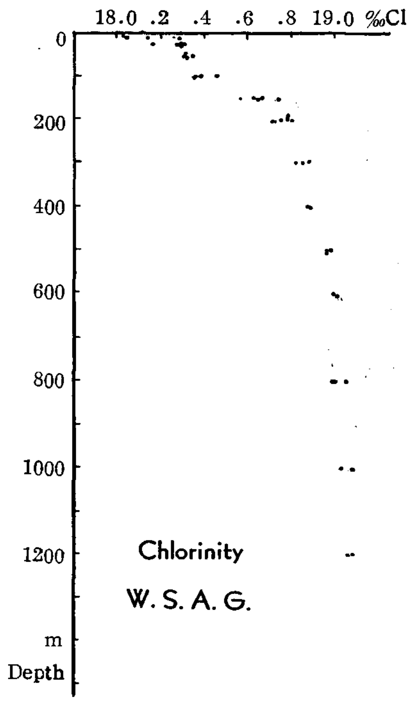
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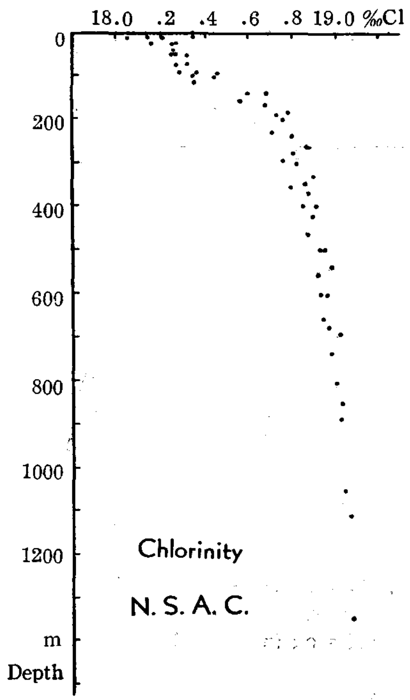
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4. Structure of Waters

More details will be presented for the characteristic layers in horizontal and vertical features.

a) Surface Layer

Near the northern continental shelf of the Bering Sea there are often encountered two stratified minima of temperature. Several records obtained are shown in Fig.10-a together with the vertical distribution of the chlorinity.

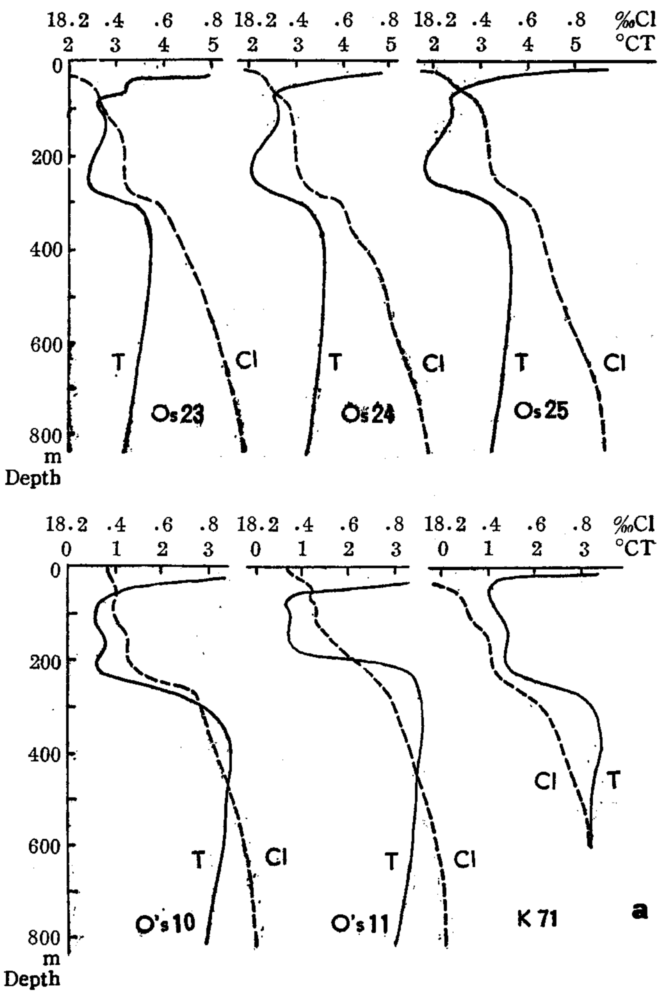

Fig. 10. (a) Vertical distribution of temperature and chlorinity at six stations in the northern region near the continental shelf in the Bering Sea.

The upper cold layer found at a depth of about 75 meters is less saline by about 1 ‰ Cl than the lower one which lies just above the halocline indicating the character of the bottom of the convection layer in the winter. Such a feature of the stratification of the waters may be attributed to the advection and lateral mixing of the more cooled and less saline water on the shallow continental shelf after the winter. Fig. 10-b shows the T-Cl curves for these waters suggesting the process of isentropic mixing. Thus, near the continental shelf, for the upper layer from the surface to the upper cold layer the water is much affected by the continental water. The area of the chlorinities below 18.3‰ in Fig. 11-b may be regarded to have been affected by the continental water.

It is almost impossible to obtain simultaneous patterns of the distribution of tempera-

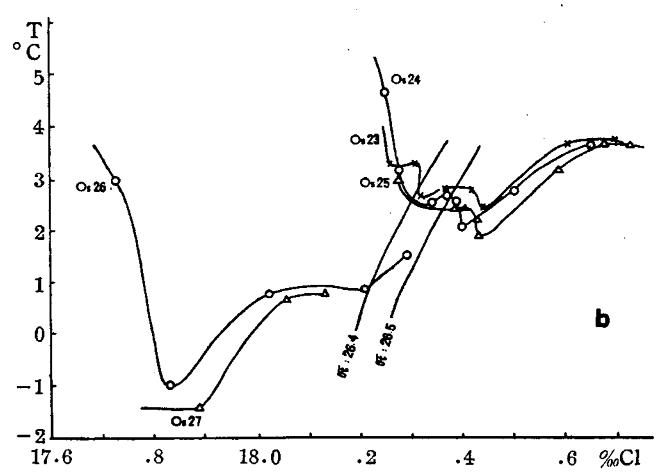

Fig. 10. (b) Temperature-chlorinity curves at several stations on and near th continental shelf showing the lateral mixing of waters at these stations.

ture and chlorinity on the present data since the observations ranged over a month. It has been reported that the surface temperature, in the early summer, rose about 1.5°C for twenty days in the Aleutian region (Watanabe, 1955). Glancing at all of the data used now, on the other hand, one finds that within a thin surface layer, from surface to 10 meters or 25 meters, waters often have been made nearly uniform at some places perhaps by wind action. To obtain more likely patterns of the temperature and chlorinity at the surface, therefore, the mean values of these at the surface and the 10-meter level are considered to be more suitable than themselves at the surface. The distribution of such mean values of temperature and chlorinity in the regions occupied during the first decade of August is shown in Fig. 11-a. Comparison of these two figures at the surface and the 50 meter layer shows that the charactaristic features of the former are entirely different from the latter, showing remarkably higher temperatures of the low saline waters near and on the continental shelf where the underlying waters are coldest. The lowness of the chlorinity of the surface water may be possibly due to ice melting after vernal heating, however, then the temperature would have been as low as that of the lower water. In Fig. 12 the difference of the temperature and chlorinity of the two layers are shown. It will be noticed that comparatively larger difference in temperature occurs in the region of the larger difference in chlorinity. From this fact it may be assumed that the surface layer of lower chlorinity has been more warmed because the larger vertical stability owing to the larger gradient of the chlorinity distribution prevents thermal diffusion downward.

Inshore the Aleutian Islands, in general, the surface water is lower in temperature and higher in chlorinity than corresponding values on both sides. As stated before, the Pacific water, as a whole, enters the Bering Sea passing through the channels between the Islands, however, on the other hand, Barnes and Thompson (1938) has stated that the Bering water near the Islands flows into the Pacific as an ebb-tide reversing to the Bering on a flood-tide. Thus the passing of the water through the channels decreases the temper-

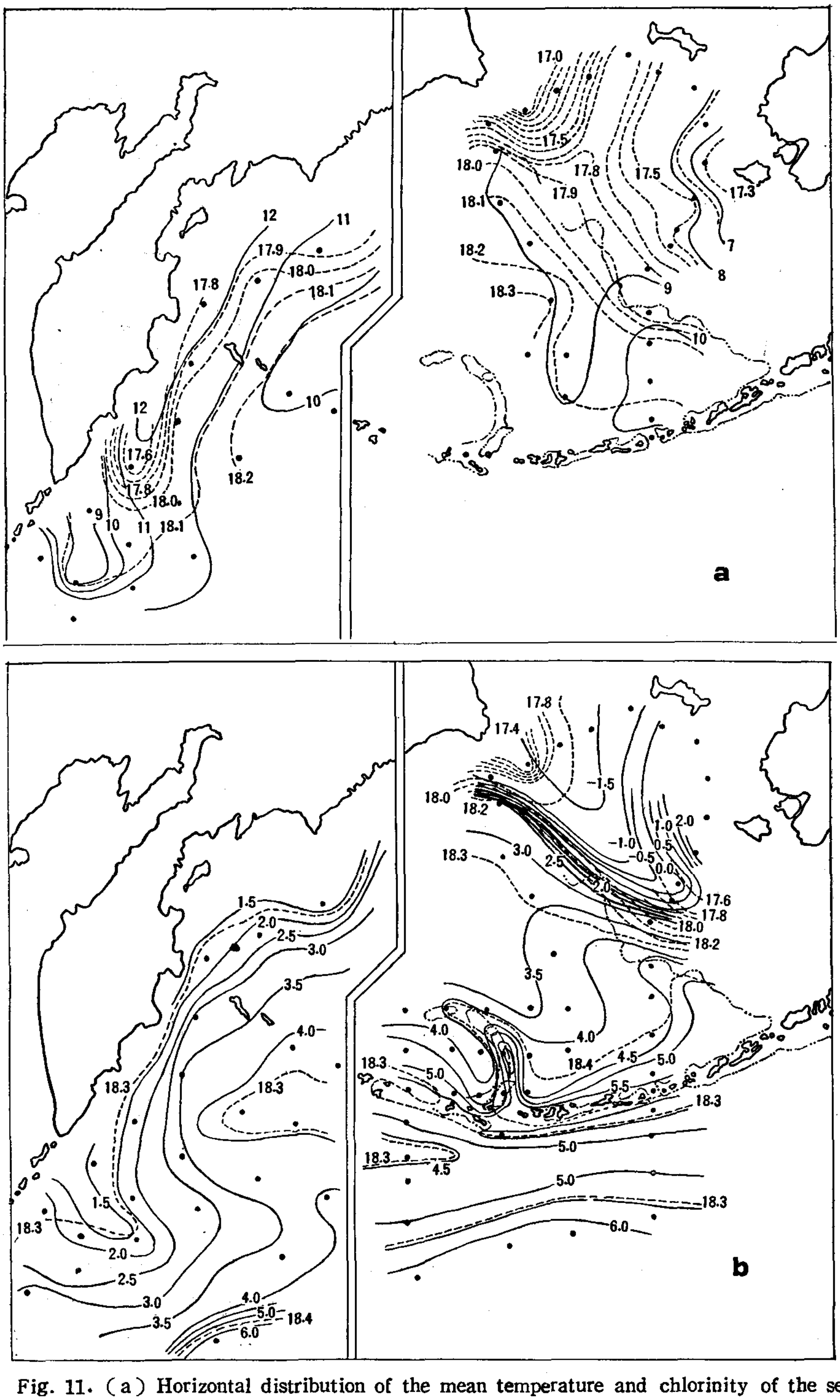

Fig. 11. (a) Horizontal distribution of the mean temperature and chlorinity of the sea surface and the 10-meter level in the first decade of August.

(b) Horizontal distribution of temperature and chlorinity at the 50-meter level.

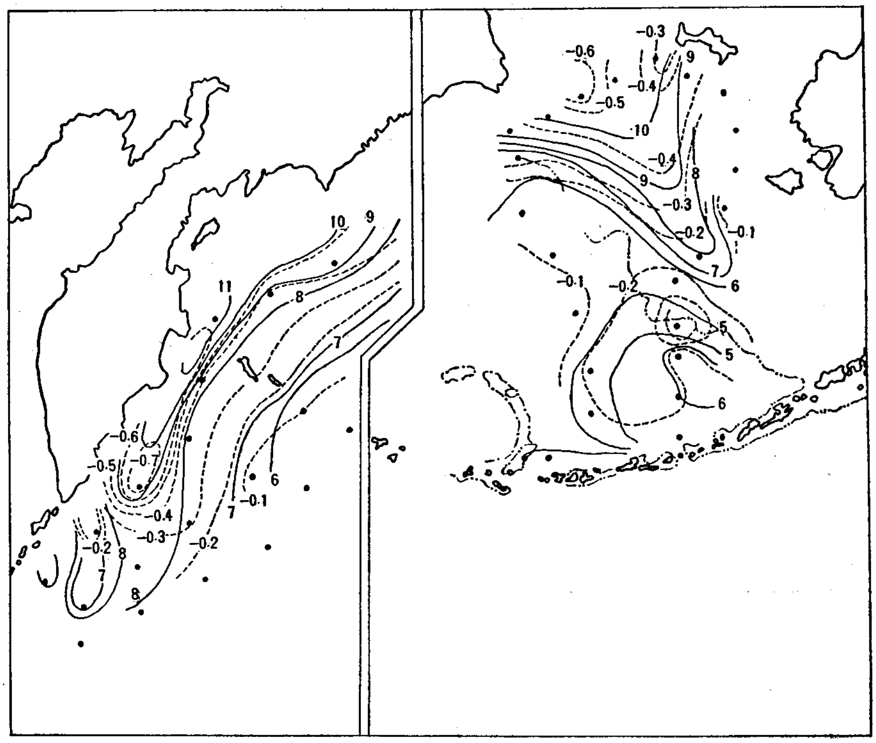

Fig. 12. Temperature and chlorinity difference of the surface (mean values taken as shown in Fig. 11-a) and the 50-meter level.

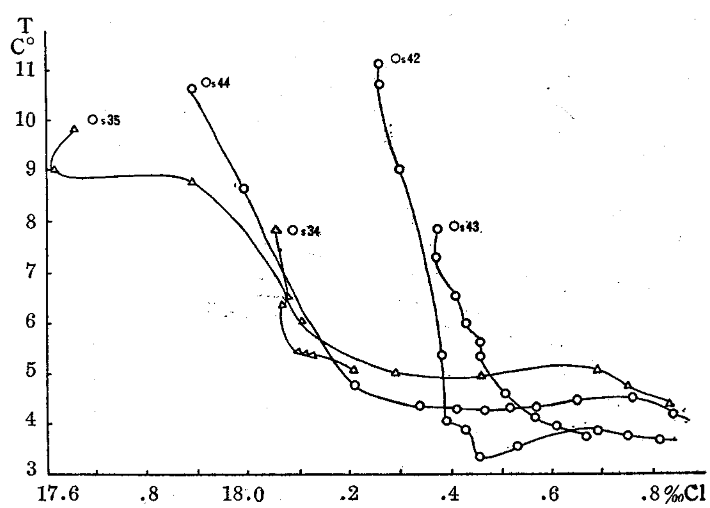

Fig. 13. Temperature-chlorinity curves at several stations occupied on and beside the Aleutian Ridge showing the vertical mixing when the water of either side of the Ridge passing over the ridge.

ature and increases the chlorinity at the surface layer in consequence of vertical mixing as seen in the several observations. Reversing in the lower layers, the water becomes rather uniform in the channels, therefore, its T–Cl curve is shortened resembling that on either side of the Islands where the water has come from. As examples several curves are shown in Fig. 13. For the reason above mentioned, the water on the northern side of the Aleutian Islands is scarcely found to have such a low chlorinity as that in the Alaska Current.

b) Dichothermal Layer

The relatively warm water of the Alaska Current has scarcely been cooled so intensively as to contain a dichothermal layer in the summer in the course of its flowing westward in the eastern region. To the west of St.Os4 in the western portion of this current can be found the dichothermal layer having a temperature below 4°C.

The distribution of the minimum temperatures and their depths are shown in Fig. 14. The coldest water is encountered in the northern region and off Kamchatka; the westerly wind in the winter would have cooled the water most severely in such region exerting the convection down to the deep. As seen in Figs. 7 and 9, on the other hand, the chlorinities of the dichothermal waters are almost 18.4‰ or so in spite of the difference of their depths. This is probably due to such distribution of a less saline water in the surface layer before winter as seen in the summer now.

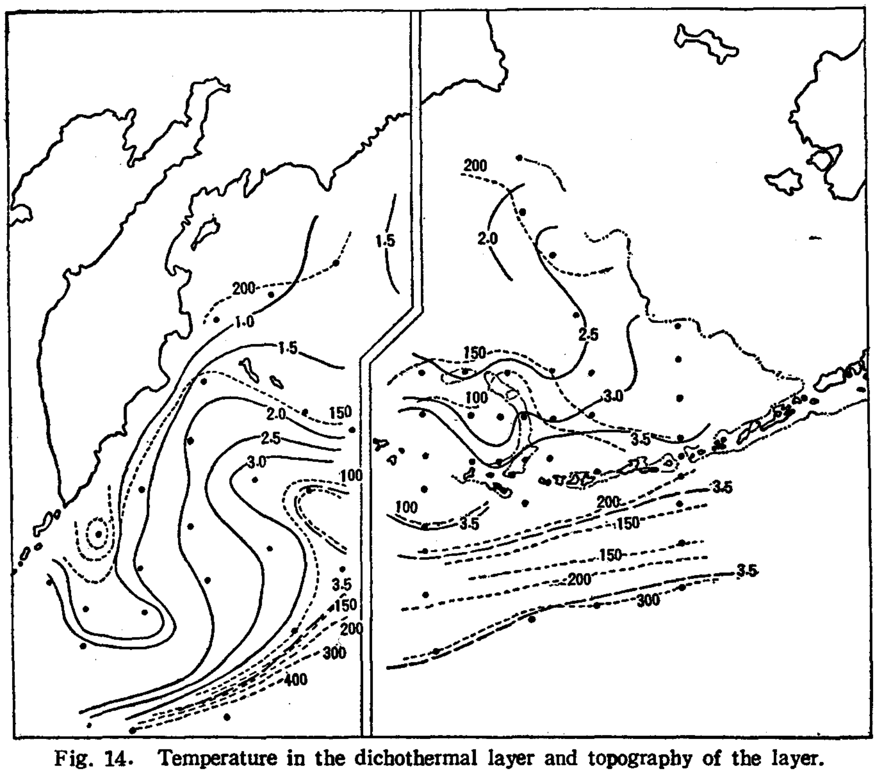

Fig. 14. Temperature in the dichothermal layer and topography of the layer.

In these values of temperature and chlorinity the dichothermal waters have various values of σ_t, the colder one the larger σ_t, since their chlorinities are almost the same. The

T-Cl curves for Sts. Os19-25 on the north-south section in the central Bering Sea, shown in Fig. 15-b, clearly represent the decreasing of σ_t toward the southern warm water from the northern cold water. Therefore, the minimum temperature waters are not to be considered to have been formed by the lateral mixing but they must be the bottom of the convection layer cooled in the previous winter, though, in the vertical profile of the temperature and chlorinity, the dichothermal layer seems to diffuse and spread southward from a northern origin. Uda (1935) has debuced that the dichothermal layer which is found in the cold Oyashio region and the Okhotsk Sea has been formed by the convection in the winter from the fact that the temrerature and salinity as well as the dissolved oxygen in the dichothermal layer are similar to those at the surface in the winter.

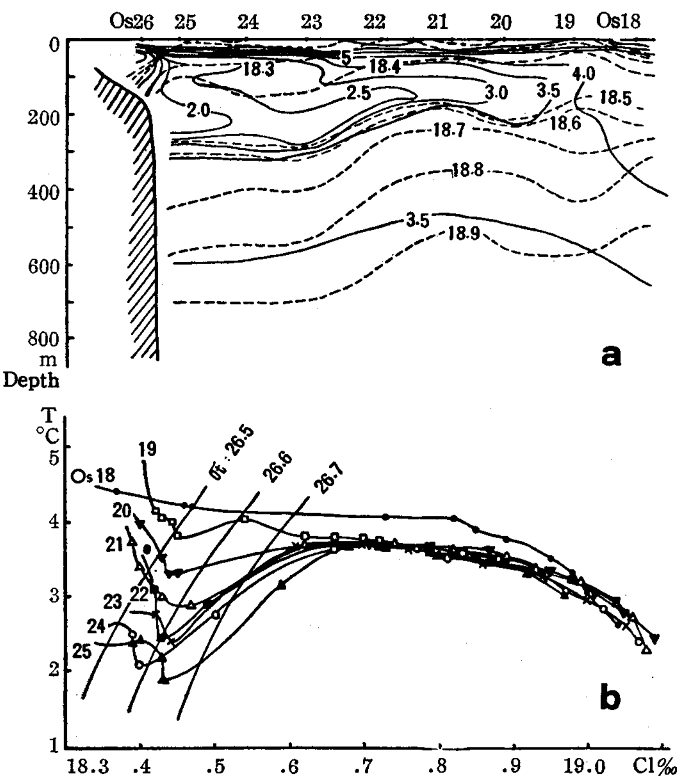

Fig. 15. (a) Temperature and chlorinity distribution in a longitudinal section through the central Bering Sea comprising Sts. Os 18-26.
(b) Temperature-chlorinity curves for stations in the section.

In Fig. 14, the isotherms drawn with the broken lines represent the minimum temperature of another character in the northern Subarctic Current and the Alaska Current as stated priviously. They come out from the southern edge of the Western Subarctic Gyral toward the east in the northern Subarctic Current sinking toward the south. The water of minimum temperature in the northern Subarctic Current, with reference to Fig. 7, is formed by mixing of the lower water of the Western Subarctic Gyral. In the Alaska Current, the layer of minimum temperature is formed by mixing of the water near the convection layer of the northern Subarctic Current as seen evidently in Fig. 7.

However, the appearance of them may be unstable.

c) Layer of Maximum Temperature

The distribution of the temperature in the layer of maximum temperature and the topography of the layer are shown in Fig. 16. In most of the area of the Bering sea, the layer appears at the 300-meter level and sinks down to below 400 meters in the northern portion where the dichothermal layer lies below 200 meters. The lowest temperature of this layer is encountered in a value of 3.41°C at the 400-meter depth at St. K71 where the minimum temperature is 1.37°C at the 200-meter depth. Off the Kamchatka Peninsula where the dichothermal layer lies at 100 to 150 meters with the temperature of below 1°C, the maximum temperatures are about 3.5°C at a depth of 300 meters. Thus, the value of the maximum temperature is varied by the vertical mixing depending upon the depth and the temperature of the dichothermal layer above it. As a result, the maximum temperature in the Bering Sea is never found decreased below 3.4°C.

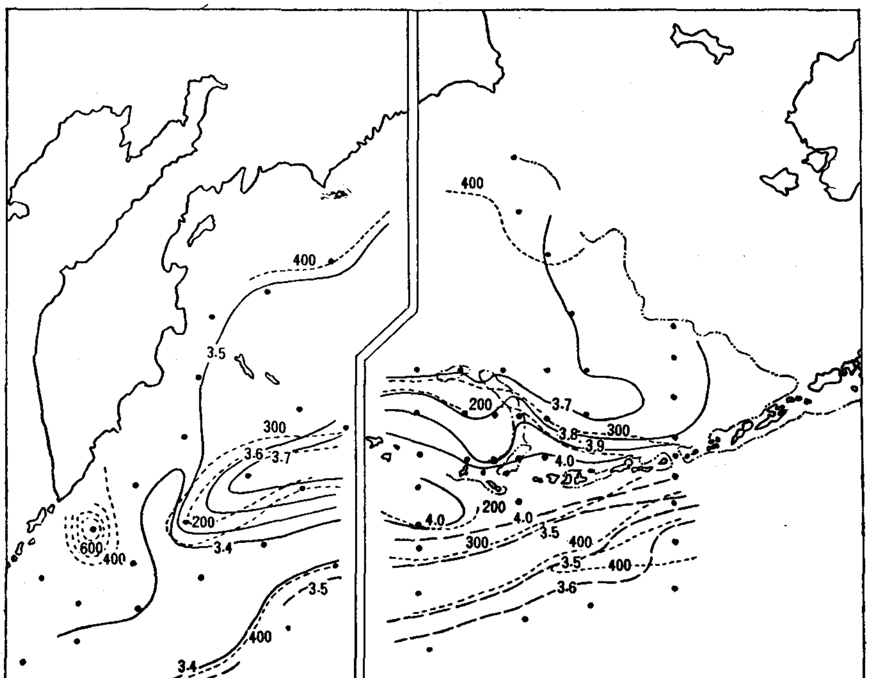

Fig. 16. Temperature in the layer of maximum temperature and topography of the layer.

In the Western Subarctic Gyral the water is quite different from that in the Bering having a maximum temperature slightly below 3.4°C, whereas the temperature of the dichothermal layer is about 2°C higher than in the Bering Sea. Accordingly, for the formation of this water one must take into account either the admixture of a more cold water of another origin or a continuing process of vertical mixing of the Bering water in

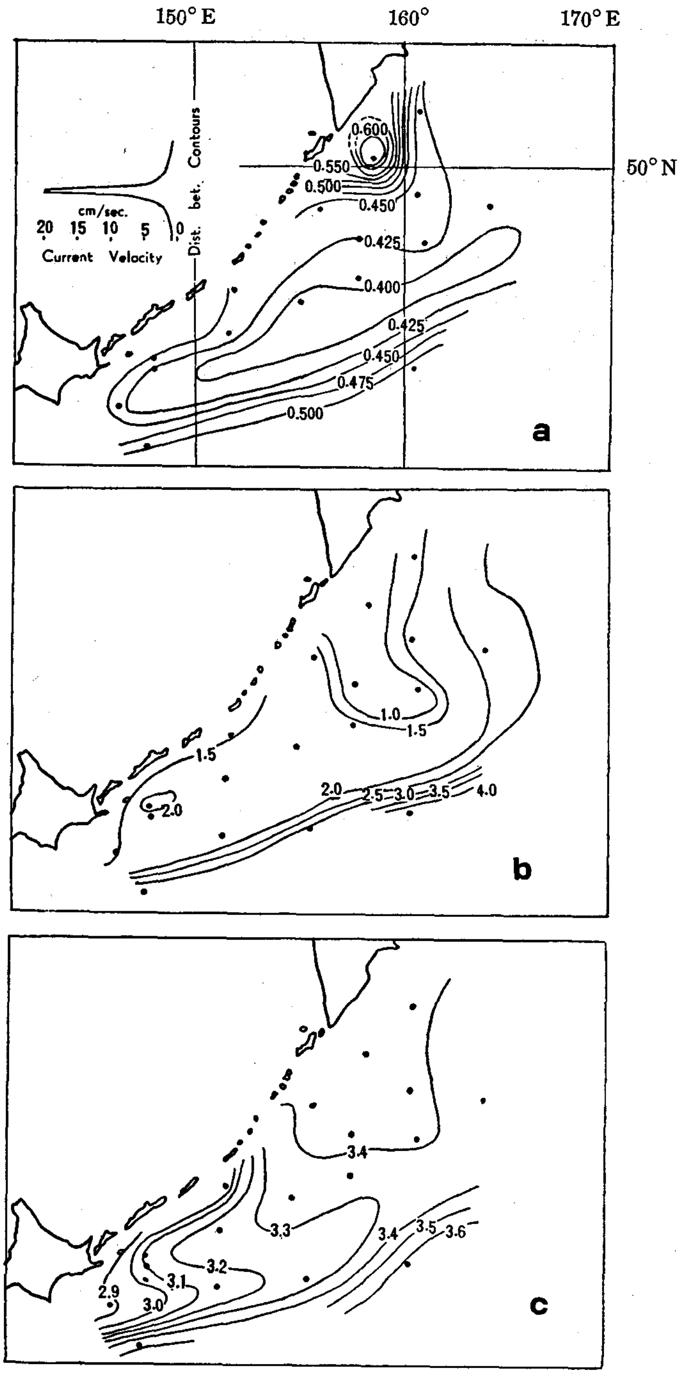

Fig. 17 (a) Geopotential topography of the 300-decibar surface relative to the 800-decibar surface according to observations of the "*Komohashi*" on June 17 to August 12, 1936.
(b) Temperature in the dichothermal layer.
(c) Temperature in the layer of maximum temperature.

the course of its flowing.

To carry a more extensive study into the further southwestern region, for that purpose, the current patterns at the 300-meter level and the distribution of both minimum and maximum temperatures are drawn in Figs. 17a-c using the data obtained during the period from June to August in the 1936 cruise of the "*Komahashi*".

As seen in the figure, the Western Subarctic Gyral occurs in a large area on the northern side of the Subarctic Current. Near the southern Kurile Islands, the isotherm of 1.5°C in the dichothermal layer suggests the flowing out and mixing of the Okhotsk water as asserted by Uda (1935), however, over the large area of this gyral, the dichothermal layer is 1.8° to 2.0°C in temperature, being accepted as a type of water which has been formed in this circumstance. At the layer of maximum temperature, a transition of the temperature is seen clearly off the middle portion of the Kurile Islands, indicating the outflow of the cold Okhotsk water; there mixing together they flow southwestward along the southern Kurile Islands. When part of this mixture is turned toward the east off Hokkaido along the Subarctic Current its temperature is 2.85°C. Increasing the temperature by lateral mixing with the water of the Subarctic Current, the mixture flows northeastward on the right part of this gyral.

Thus the lower water of the Western Subarctic Gyral has decreased the temperature as a result of mixing with the water of the Okhotsk Sea. Saito (1952) has inferred that the intermediate water in this region is a mixture of the intermediate waters of the Okhotsk and the Bering Sea from the fact that the T-S curves of the intermediate water in the region are implied between the mean T-S curves in the Okhotsk and the Bering Sea.

The water of the northernmost portion of the Subarctic Current is a mixture of all these waters.

In the lower layers all over these regions, the water of the Alaska Current decreases in chlorinity because of vertical mixing going on in the Bering circulation as treated mathematically by Hirano (1957); further, flowing off the Kurile Islands it becomes more diluted by mixing with the Okhotsk water. In the Western Subarctic Gyral, thus the water has been diluted, however, it shows rather higher chlorinity than the surrounding waters at the same levels on account of the ascending motion taking place in the gyral. Showing such a feature, the distribution of chlorinity at the 300-meter level is presented in Fig. 18. In the Bering, moreover, the development of the convection in the winter may more effect the mixing with the lower layer, since the chlorinity is lowest at the northern region where the dichothermal layer lies deepest while toward the southwest it increases again on the

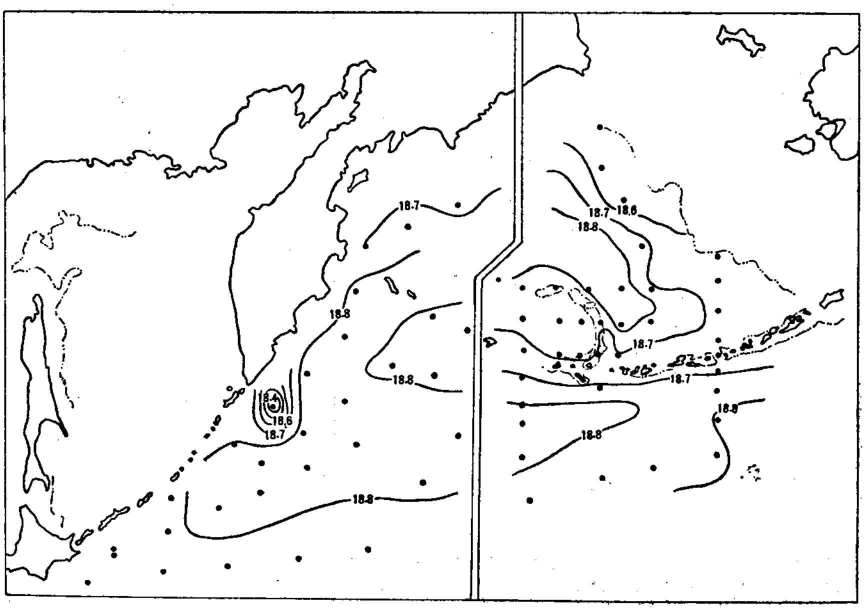

Fig. 18. Horizontal distirbution of chlorinity at the 300-meter level.

current along Kamchatka.

The ranges of the values in the vertical distribution in these regions are to be compared with each other in Fig. 9 previously shown.

5. Summary

On the basis of data obtained by the "*Oshoro Maru*" in 1956 and the "*Komahashi*" in 1936, descriptions and considerations have been given to the current systems and the structure of waters in the Bering sea and the Aleutian region, which are summarized as follows:

1) Along the southern side of the Aleutian Islands, the Alaska current, which originates in the Gulf of Alaska, flows westerly. The major part of this current flows into the Bering Sea close to the west of Attu Island and through the western channels. In the Bering Sea, waters from the Pacific take counterclockwise circulation, and then flow out along the Kamchatka Peninsula toward the southwest. Between this flow from the Bering and the easterly Subarctic Current, a counterclockwise gyral, named the Western Subarctic Gyral in this paper, occurs. On the continental shelf off Alaska, the water flows northward, however, part of it turns toward the southwest and flows along the Asiatic coast.

2) The waters in these regions, referring to the T-Cl curves, are classified into five groups. The distribution of them corresponds to the current systems above stated.

3) The water of the Alaska Current is relatively warm, and has low chlorinity in the surface layer. In the eastern portion of this current, the water has scarcely been cooled so intensively as to contain a dichothermal layer in the summer. An indistinct layer of minimum temperature is formed below the convection layer by mixing of the water of the northern Subarctic current.

4) Inshore the Aleutian Islands, the surface water is lower in temperature and higher in chlorinity than corresponding values of both sides in consequence of the vertical mixing when the water passes over the ridge.

5) On the shallow continental shelf in the Bering, the water has been severely cooled to below 0°C, and has extremely low chlorinity especially at the surface in summer. However, the surface in this region, as well as in the coastal region of Kamchatka, is more warmed than the central Bering because of the larger vertical stability in summer.

6) In the Bering basin, the dichothermal layer is very distinct; its temperature ranges 1° to 3°C, the depth ranges 100 to 250 meters, and in the northern portion the temperature is lowest and the depth is deepest. The dichothermal layer in this region, as well as that in the Western Subarctic Gyral, characteristically indicates the bottom of the convection layer formed in the previous winter. Near the northern continental shelf, there are encountered two minima of temperature of which the upper one is attributed to the mixing of the more cooled water on the continental shelf. The muximum temperature in the lower

layer is never found decreased to below 3.4°C even at the lowest in the northern portion.
7) In the Western Subarctic Gyral, the temperature of the dichothermal layer is about 2°C, and the depth is 100 meters, nevertheless the maximum temperature lying at the 300-meter level is lower than the lowest in the Bering. The lower water in this region is a mixture of the lower waters of the Bering and the Okhotsk Sea.
8) In the northern Subarcric Current, an indistinct layer of minimum temperature appears below the convection layer, and for all lower layers the temperature is lower than in the Alska Current. The lower water in this region is a mixture of the lower waters of the Subarctic Current and the Western Subarctic Gyral.
9) In the lower layers all over the regions, the water of the Alaska Current decreases in chlorinity because of vertical mixing going on in the Bering circulation, especially in the northern portion of the Bering owing to the development of the convection in the winter. In the Western Subarctic Gyral, the water has been more diluted by mixing of the Okhotsk water, however, it shows rather higher chlorinity than the surrounding waters on account of the ascending motion taking place in the gyral.

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