HOKKAIDO UNIVERSITY

Title	Turbidity Distribution of the Bering Sea in the Summer
Author(s)	KAWANA, Kichiichiro
Citation	北海道大學水産學部研究彙報, 26(1), 73-86
Issue Date	1975-06
Doc URL	http://hdl.handle.net/2115/23548
Type	bulletin (article)
File Information	26(1)_P73-86.pdf

Instructions for use

Hokkaido University Collection of Scholarly and Academic Papers : HUSCAP

Bull. Fac. Fish. Hokkaido Univ.
26(1), 73-86. 1975.

Turbidity Distribution of the Bering Sea in the Summer

Kichiichiro KAWANA*

Abstract

The vertical and horizontal distributions of turbidity were measured in the Bering Sea by using *in situ* turbidity meters, during the 24th and 28th cruises of the T.S. *Oshoro Maru* in 1967 and 1968.

It was found from continuous measuring that the turbidity of the ocean water varies very smoothly and continuously in the horizontal direction.

The vertical distribution of the turbidity tends to be nearly uniform in the convection layer and then changes suddenly at the thermocline. The thermocline presents a firm barrier against the downward transport of suspended material. Below the thermocline, turbidity decreases gradually with depth increase whereas in the shallow continental shelf it increases toward the bottom due to the disturbance of the water flow.

The water masses of the Bering Sea can be classified into the following four types from the turbidity distribution; turbid water of the northern side of the Aleutian Islands, clear water of the Bering basin, water of the continental shelf and the coastal water near Bristol Bay.

Introduction

Studies on the turbidity of sea water and suspended matter in the sea are regarded as important in several fields of oceanographic research, i.e. water mass analysis, stratification of waters, propagation of light, phytoplankton production, etc..

Many measurements of turbidity have been reported from early days with the use of optical methods. Joseph[1] measured the extinction coefficient of sea water *in situ*, using a turbidity meter and attempted to explain the change of turbidity in the sea from the diffusion theory of suspended matter. Jerlov[2),3)] sampled sea water and measured its light transparency and light scattering by the use of a Tyndall meter. Fukuda et al.[4] designed an *in situ* turbidity meter and measured the turbidity distribution in the North Pacific and the Bering Sea. Nishizawa et al.[5,6] reported the relation between the turbidity distribution and some oceanographic factor in the Eastern China Sea and in the Subarctic Water of the North Pacific.

In recent years, Ewing and Thorndike[7] observed the turbid layer near the ocean floor by an *in situ* photographic nephelometer. This turbid layer was called

* *Research Institute of North Pacific Fisheries, Hokkaido University*
(北海道大学水産学部北洋水産研究施設)
Present: *Government Industrial Research Institute, Chugoku*
(現在: 中國工業技術試験所)

the nepheloid layer. Eittrein et al.[8] also observed this layer in the North American Basin. In the Arctic Ocean, Hunkinks et al.[9] showed that there is a close relationship between the nepheloid layer and bottom currents. Pak et al.[10] measured the light scattering of sea water in the upwelling area and studied temperature inversion. Neuymin[11] reported overall information about the inhomogeneities of optical properties in deep ocean water. Takematsu et al.[12] measured the suspended matters in the sea water off the coast of Tokai Mura and put into sufficient evidence the relation between these properties and the distribution.

The present author carried out the turbidity measurements in the Bering Sea with an *in situ* turbidity meter during the observation cruises of the T.S. *Oshoro Maru* in the summers of 1967 and 1968. The Bering Sea is very good fishing ground for salmon and many oceanographic investigations have been reported. (for instances, Koto and Fujii[13], Uda[14], Dodimead et al.[15], Ohtani[16]) In this paper, the obtained results are described in relation to the turbidity distribution and some oceanographic conditions.

Method of Measurement

During the oceanographic observation cruise of 1967, the vertical and horizontal distributions of turbidity were measured. The measurements of the vertical distribution were carried out from surface to a depth of about 70 m by an *in situ* turbidity meter designed by Nishizawa[17]. The horizontal distribution was measured continuously with a turbidity meter which was placed in a laboratory room of the T.S. *Oshoro Maru*. The room was equipped with pipes which were connected to the bottom plate of the boat and opened to the sea water underneath. Water was sucked through the pipe automatically and continuously by hydrostatic pressure difference. The sea water, passing through the pipe and a rubber tube, flowed into the plastic tube of the turbidity meter. The measurements

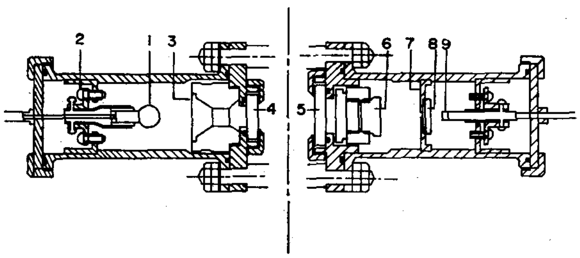

Fig. 1. Diagram of the turbidity meter. The left side shows the lamp chamber and the right side the photocell chamber. 1: lamp, 2: lamp adjustment screw, 3: collimating lens, 4: window glass of the lamp chamber, 5: window glass of the photocell chamber, 6: collimating lens, 7: pinhole, 8: red filter (Kenko R2), 9: CdS-photoresistor.

of turbidity were begun right after the ship's departure from a hydrographic station and continuous records were obtained until the next station was reached. The read-out of the turbidity meter gave average values of the turbidity of surface water always at the same interval of about 500 m, because the boat speed was almost constant during the entire cruise. This meter was designed by Tan[18]. Both turbidity meters mentioned above consist of photocells and red colour filters (Kenko R2) and have a peak sensitivity at the wavelength of 650 mμ.

During the cruise of 1968, the vertical distribution of turbidity and temperature were measured simultaneously by an *in situ* turbidity meter equipped with a thermistor. That turbidity meter was a common type, its optical system consisting of a lens-pinhole system as is shown in Fig. 1. The light source was a tungsten lamp (6V, 1A) and the light flux from the lamp was converted to a parallel beam by a collimator lens (f=50 mm). The light path was 50 cm and the transmitted light through the sea water was converged by a lens (f=50 mm). The converged light passed through the pinhole and the red colour filter (Kenko R2) and reached the detector. The detector of this meter consisted of a CdS-photoresistor. The electrical circuit of this meter is shown in Fig. 2. The upper and lower portion of the figure show the bridge circuit of the turbidity meter and the lamp circuit respectively. The compensation system which takes care of a variation of electric voltage is composed of another pair of a lamp and a photoresistor. Main and compensation photoresistors are connected as two elements in

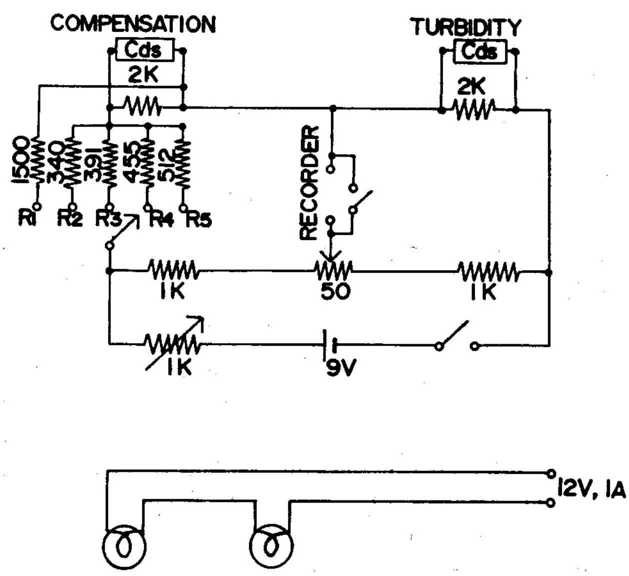

Fig. 2. Diagram of electric circuit of turbidity meter. The upper circuit shows the birdge circuit of the turbidity meter and the lower its lamp circuit.

the Wheatstone bridge. The difference of their output is fed into a recorder.

The calibration of this meter was carried out at the laboratory using sevral neutral filters. After the adjustment of the detector circuit in the air, the underwater unit was placed in a tank filled with distilled water. Then several neutral filters of different density were inserted in the light path. The density of each neutral filter was determined by the ratio of the resistance values of the photoresistor of the turbidity meter before and after the insertion. The relation between the resistance value C and the light intensity I is given in the following empirical formula.

$$I = 204.2 \times C^{-1.17}$$

Next, both photoresistors of the turbidity meter and of the light compensation were connected in the Wheatstone bridge and the reading of the meter was taken. This procedure was repeated with each neutral filter. Finally, a transmission measurement of a sample of the distilled water used to fill in the tank was made by the use of a laboratory spectrophotometer with a 10 cm cell.

In this paper, the turbidity distribution is discussed in relation to the values substracting the attenuation by water alone from measured values. The attenuation coefficient by water alone is adopted 0.30 per meter at 650 mμ from the measurement by Dawson and Hulbert[19].

Results and discussion

The locations of the hydrographic stations of the cruise 24 and 28 of the T.S. *Oshoro Maru* in 1967 and 1968 are shown in Fig. 3. Temperature and salinity were measured at all hydrographic stations. The measurements of the vertical distribution of turbidity were carried out using the *in situ* turbidity meter at the stations marked with filled circles in Fig. 3. The measurements of both cruises were done mostly in June south of 60°N and in July north of it. In the latter region, the opportunities to use the turbidity meter were very few because of bad weather. Therefore the turbidity distributions are discussed mainly for the region south of 60°N.

The geopotential topographies of the 10-decibar surface relative to the 800 decibar surface in 1967 and 1968 are shown in Fig. 4. On the shallow continental shelf, the geopotential topographies of the 10-decibar surface relative to the 50-decibar surface are also shown in the same figure. It is well known that the Alaskan stream, which originates in the Gulf of Alaska, flows westward along the southern side of the Aleutian Islands. The major part of this stream enters the Bering Sea close to the west of Atuu Islands and through the channels between the Islands. As is evident from Fig. 4, the Alaskan stream moves toward the east or northeast along the northern side of the Aleutian Islands in the Bering Sea, and

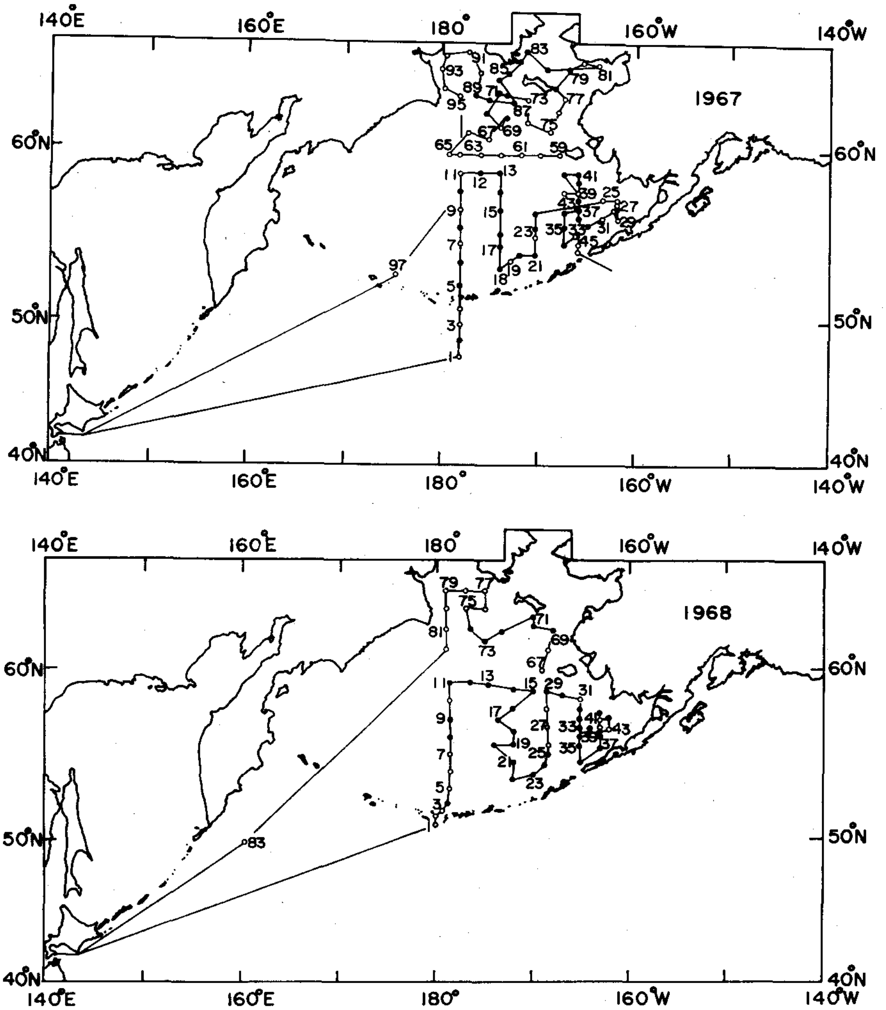

Fig. 3. Hydrographic stations of the cruises of the T.S. *Oshoro Maru* to the Bering Sea in 1967 and 1968.

then swings northwesterly along the bottom contour forming a large counter-clockwise circulation. It is well known that the region along the northern side of the Aleutian Islands is the complicately mixing area of the easterly flow and the inflow water through the channels. During both cruises, small counter-clockwise eddies are formed in the large circulations. These are seen at 45°N, 173°W in 1967 and 56°N, 172°W in 1968.

On the shallow continental shelf, most water flows northward, however a part of it perhaps turns toward the southwest, and then flows southwestward along the Asiatic coast. A part of the northward flow passes through the Bering Strait.

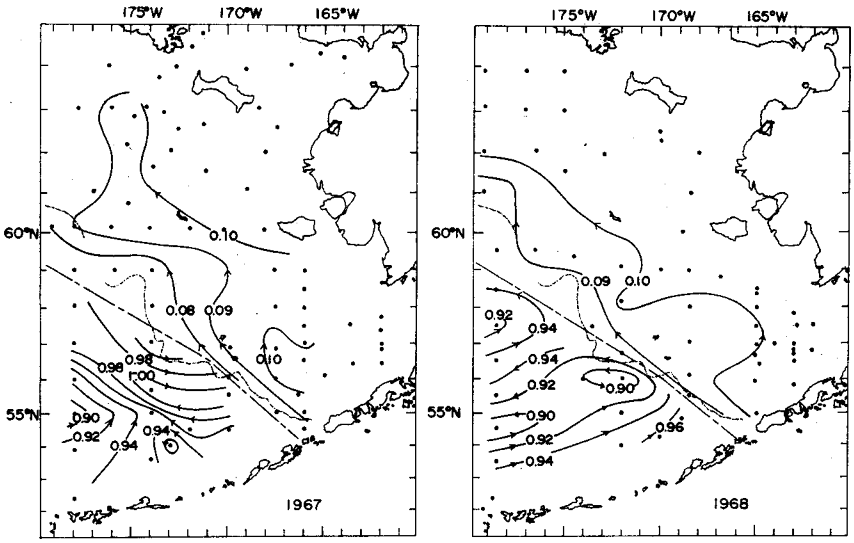

Fig. 4. Geopotential topographies of the 10-decibar surface relative to the 800-decibar surface in 1967 and 1968. On the shallow continental shelf are shown geopotential topographies of the 10-decibar relative to the 50-decibar surface.

1. Continuity of the turbidity

The horizontal distribution of turbidity of the surface water obtained by continuous measurements in 1967 is shown in Fig. 5 and Fig. 6. The data of Fig. 5 was obtained from Station 5 to Station 8 on the course along the 178°W and Fig. 6 was from Station 35 to Station 38 on the course along the 167°W. The vertical and horizontal coordinates of these figures give the reading of the turbidity meter and the distance along the ship's course respectively. During the cruise, the photocell of this meter was exchanged owing to some troubles making it impossible

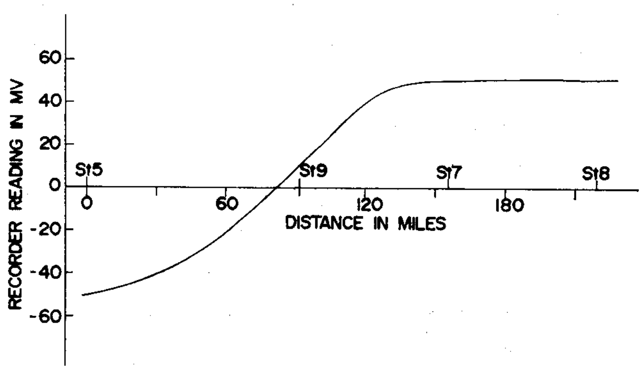

Fig. 5. Horizontal distribution of turbidity of the surface layer obtained on the course along the 178°W in 1967.

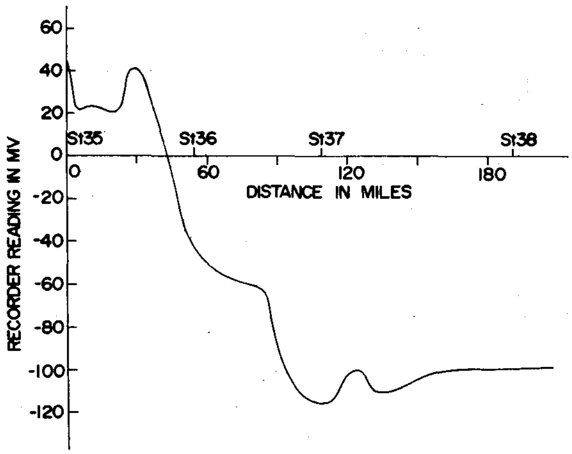

Fig. 6. Horizontal distribution of turbidity of the surface layer obtained on the course along the 167°W in 1967.

to use the calibration curve which had been drawn up before the cruise. The level of turbidity was shown as the reading of the trubidity meter. The reading decreases with the increasing turbidity. Fig. 5 shows a monotone and smooth change of turbidity and Fig. 6 shows several abrupt changes of turbidity. In both figures, however, the change in turbidity is not as violent as the case for "patches". The whole distribution and change of turbidity are subject to discuss from the data obtained at the hydrographic stations which were several miles apart each other.

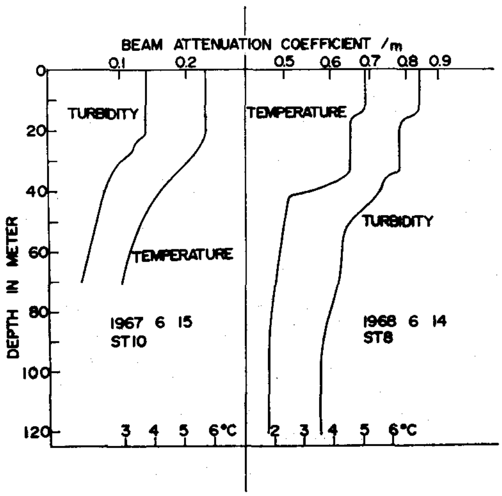

Fig. 7. Vertical distribution of turbidity at the Bering Basin.

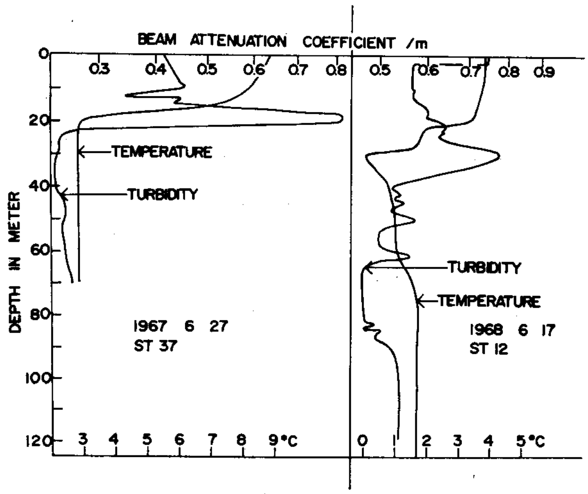

Fig. 8. Vertical distribution of turbidity at the continental shelf.

2. Vertical distribution

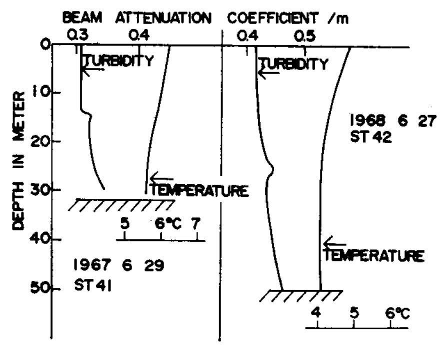

Fig. 9. Vertical distribution of turbidity near the coast.

The typical pattern of vertical distribution of turbidity and temperature obtained at the Bering basin, the continental shelf and the coastal area are shown in Fig. 7, and Fig. 8 and Fig. 9 respectively. It is seen from the temperature distribution that the convection layer in this area has a thickness of 20 to 30 m, and the thermocline is formed at the bottom of the convection layer. The turbidity is nearly uniform down to the thermocline and then it changes suddenly with the gradient similar to that of temperature. The thermocline works as a firm barrier against the downward transport of the suspended material. Most of the suspended particles stay inside the convection layer and accumulated at the thermocline where the change of density is abrupt. It is postulated that among those particles inorganic matter coheres and sinks down piercing through the thermocline whereas organic matter stays and decays inside the convection layer.

The turbidity of the Bering basin water is relatively low. The temperature jumps as well as turbidity changes at the thermocline are smaller than those at other areas. The gradient of turbidity change is quite similar to the temperature gradient. It is considered that the turbidity can be an effective parameter of water mass analysis in the same manner as temperature.

As is evident from Fig. 8, the maximum of turbidity is found at the thermocline clearly showing that the accumulation of the suspended matter was formed at the thermocline. The fine fluctuations of turbidity are also observed on the right hand side of Fig. 8.

Fig. 9 shows turbidity distribution of very shallow coastal area. The turbidity and temperature are almost uniform from the surface to the bottom because of a vertical mixing. But near the bottom, the turbidity increases due to the upward transport of the sediment.

3. Horizontal distribution

Horizontal distribution of temperature and salinity at the 10-m level in 1967 and 1968 are shown in Fig. 10 and the distribution of turbidity in Fig. 11. As is observed in Fig. 10, it is the general feature of the surface layer that the isohaline lines nearly parallel to the continental shelf and decreases toward the coast. The oceanic water of high salinity influenced by the Alaskan stream is distinguished clearly from the continental shelf water by the isohalines from 33.2‰ to 32.8‰. Near Bristol Bay, there is coastal water which has high temperature attributable to the heat transfer from the sun and fresh inland water.

The comparision between the temperature in 1967 and in 1968 indicates that the former is generally higher than the latter due to the fact that ice thawed earlier in 1967. In 1968, relatively cold water influenced by ice thaw expanded from the northern side of the continental shelf to the Bering basin.

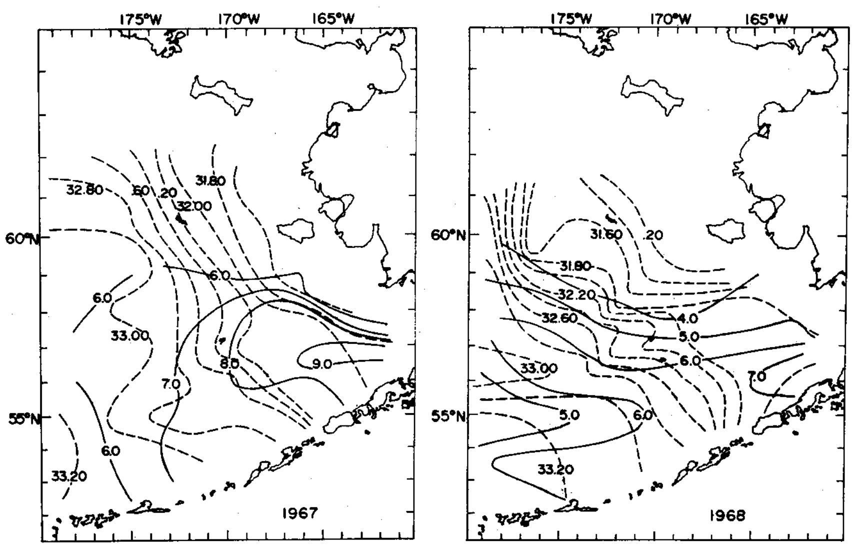

Fig. 10. Horizontal distribution of temperature and salinity at the depth of 10 meters in 1967 and 1968.

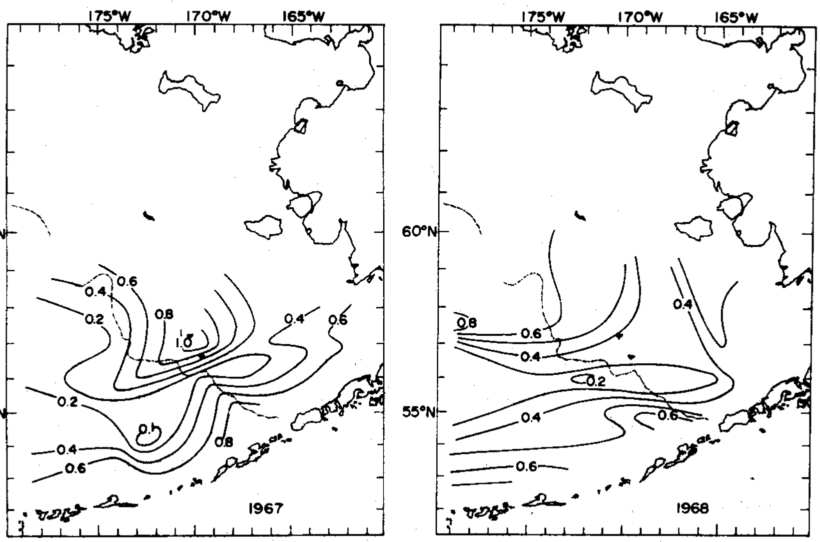

Fig. 11. Horizontal distribution of turbidity at the depth of 10 meters in 1967 and 1968.

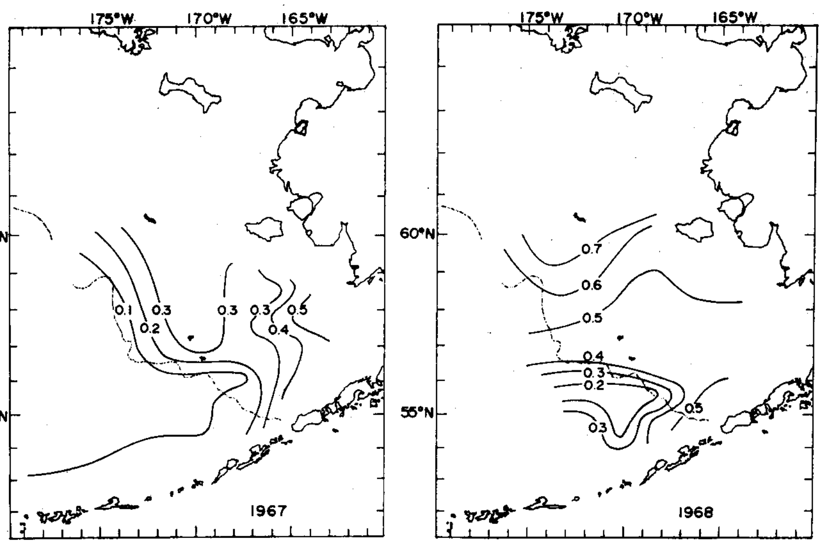

Fig. 12. Horizontal distribution of turbidity at the depth of 70 meters in 1967 and 100 meters in 1968. At the shallower stations than 70 and 100 m, values of the turbidity near the bottom are adopted.

It is seen from the distribution of turbidity that the water of the northern side of the Aleutian Islands and the continental shelf are very turbid, while water mass of the Bering basin is very clear.

The northern side of the Aleutian Islands is a complicated mixing area of

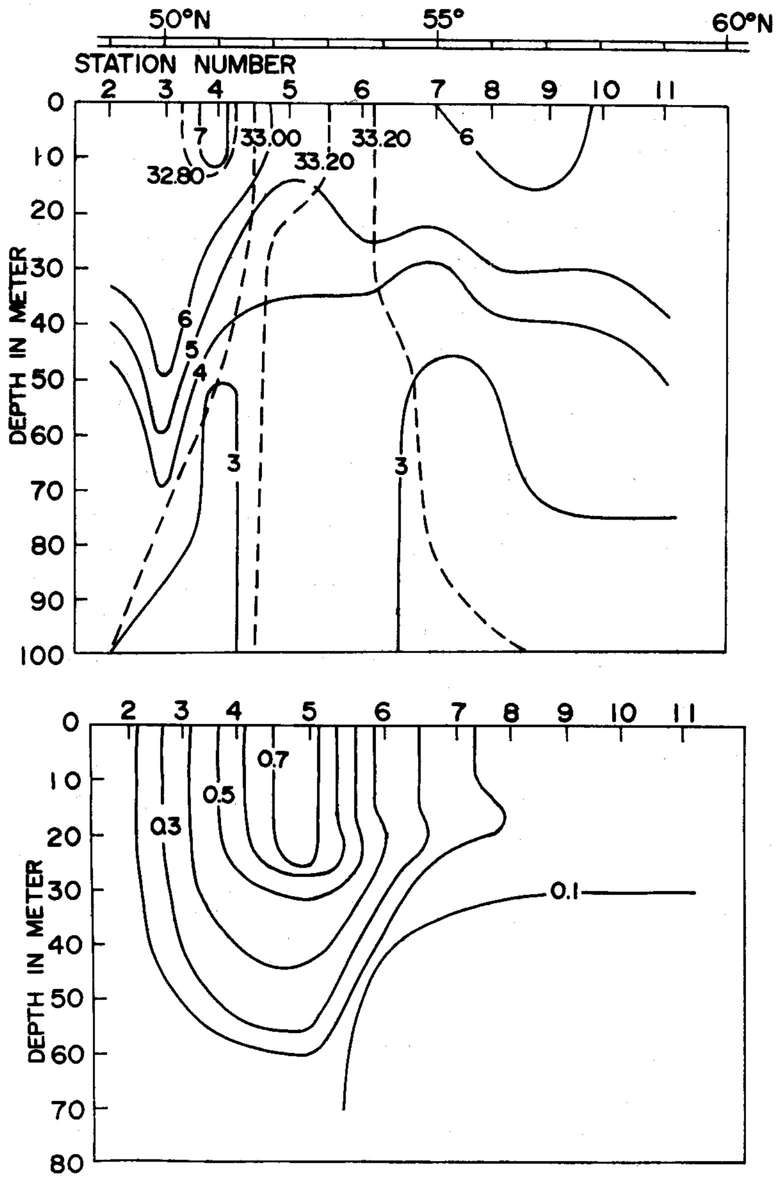

Fig. 13. Vertical sectional distribution of turbidity, temperature and salinity on the course along the 178°W in 1967.

the easterly Alaskan stream and the inflow water through the channels. The inflow water is clearly recognized from the distribution of turbidity near the Unimack channel. While passing through the channels, the turbidity of sea water increases rapidly. This turbid inflow water is considered to be responsbile for the high turbidity of the northern side of the Aleutian Islands.

The oceanic water in the Bering basin is very clear and expands toward the continental shelf like a tongue. But this tongue has no counterpart in temperature and salinity distribution.

The turbid water of the continental shelf is most likely ice thawed water. There is also turbid water near Bristol Bay.

During the both cruises, the existence of a small counter-clockwise eddy which is seen in the geopotential topography (Fig. 4) is very clear. Fig. 11 presents a clean water patch in the eddy area which is due to the upwelling of clear water from the deep layer.

The distribution of turbidity at the 70 m level in 1967 and at the 100 m level in 1968 are shown in Fig. 12. On the shallow continental shelf, the distribution of turbidity near the bottom are shown in the same figures.

In the same manner as the distribution of turbidity at the 10 m level, the water mass can be classified into the following four types; water of the northern side of the Aleutian Islands, clear water of the Bering basin, water of the continental shelf and coastal water near Bristol Bay. Very turbid water is seen near the bottom of the shallow continental shelf. This is the effect of the sediments transported from the seabed.

4. Vertical sectional distribution

Fig. 13 shows a vertical sectional distribution of turbidity in 1967 which runs along longitude 178°W. The distributions of temperature and salinity are also shown in the figure. It is clear from the temperature distribution that some intermediate cold water is found on the northern side of Station 6 indicated by the isotherm of 3.0°C. The southern side of this isotherm is a complex mixing area influenced by the Alaskan stream. This region is very turbid whereas the intermediate cold water is very clear.

Conclusion

From the characteristics of turbidity, the water masses in the Bering Sea can be classified into the following four types; water of the northern side of the Aleutian Islands, clear water of the Bering basin, water of the continental shelf and coastal water near Bristol Bay. But in this study, turbidity is measured by using only an optical method so that the measured values are considerably influenced by the size distribution of particles and the light absorption by dissolved materials. These suspended matters in the sea water experience very complicated processes such as, sedimentation, dissolution, coagulation, etc.. Thus the turbidity of sea water is not a characteristic for the water mass which is conservative during a long time. It is recognized, however, that patterns of distribution of waster masses for a limited time interval can be sensibly traced on referring to the turbidity distribution.

Acknowledgements

The author would like to acknowledge the continuing guidance and encouragement of Emeritus Professor Naoichi INOUE of Hokkaido University and also thank Professor Masami ISHIDA and Professor Rihei KAWASHIMA of Hokkaido University for their helpful advice. The author thanks the captain and the crew of the T.S. *Oshoro Maru* for their kind help in the tedious work at sea during the cruises.

References

1) Joseph, J. (1949). Durchsichtigkeitsmessungen im meere im ultra-violetten spektralbereich. *Deut. Hydrograph. Z.* **2**, 212–218.
2) Jerlov, N. G. (1951). Optical studies of ocean water. *Rept. Swedish Deep-Sea Expedition* **3**, 1–59.
3) Jerlov, N. G. (1953). Particle distribution in the ocean. *Ibid.* **3**, 73–97.
4) Fukuda, M., Inoue, N. and Nishizawa, S. (1954). Investigation of trubidity in the sea. I. Design of a turbidity meter and preliminary observation. *Bull. Fac. Fish. Hokkadio Univ.* **5**, 99–104.
5) Nishizawa, S. and Inoue, N. (1958). Turbidity distribution and its relation to some oceanographical factors in the eastern China Sea in the last summer of 1956. *Rec. Oce. Works Japan.* **2**, 101–115.
6) Nishizawa, S., Inoue, N. and Akiba, Y. (1959). Turbidity distribution in the subarctic water of the North Pacific in the summer of 1957. *Ibid.* **3**, 231–241.
7) Ewing, M. and Thorndike, E. M. (1965). Suspended matter in deep ocean water. *Science.* **147**, 1291–1294.
8) Eittrein, S., Ewing, M. and Thorndike, E. M. (1969). Suspended matter along the continental margin of the North American Basin. *Deep-Sea Res.* **16**, 613–624.
9) Hunkins, K., Thorndike, E. M. and Mathieu, G. (1969). Nepheloid layer and bottom currents in the Arctic ocean. *J. Geophys. Res.* **74**, 6995–7008.
10) Pak, H., Beardsley, Jr. G. F. and Smith, R. L. (1970). An optical and hydrographic study of a temperature inversion off Oregon during upwelling. *J. Geophys. Res.* **75**, 629–636.
11) Neuymin, H. G. (1970). Inhomogeneties of optical properties in deep ocean waters. *J. Opt. Soc. Amer.* **60**, 690–693.
12) Takematsu, N., Okami, N., Kishino, M., Fukuda, M. and Sassaki, T. (1971). The distribution of suspended matter in sea water off the coastal of Tokai mura. *La. mer.* **9**, 252–259.
13) Koto, H. and Fujii, T. (1958). Structures of the water in the Bering Sea and the Aleutian region. *Bull. Fac. Fish. Hokkaido Univ.* **9**, 149–170.
14) Uda, M. (1963). Oceanography of subarctic pacific ocean. *J. Fish. Res. Bd. Canada.* **20**, 119–179.
15) Dodimead, A. J., Favorite, F. and Hirano, T. (1963). Review of the oceanography of the subarctic pacific ocean. *I.N.P.F.C. Bull.* **13**, 1–195.
16) Ohtani, K. (1969). The oceanographic structure and the ice formation on the continental shelf in the eastern Bering Sea. *Bull. Fac. Fish. Hokkaido Univ.* **20**, 94–117. (in Japanese).
17) Nishizawa, S. (1965). Sea water turbidity and suspended matterial. (unpublished).

18) Tan, H. N. (1962). Continuous profile of turbidity in the surface layer of the Tsugaru Strait and Mustu Bay obtained with a new turbidity meter. *M. F. Thesis. Fac. Fish. Hokkaido Univ.* (unpublished).
19) Dawson, L. H. and Hulbert, E. C. (1934). The absorption of ultraviolet and visible light by water. *J. Opt. Soc. Amer.* **24**, 175–177.