Chemical Studies of the Western Pacific Ocean. V. The Vertical Variation of Minor Constituents in the "Kurosio" Region. Part 1.

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Introduction. In the previous papers,[1] the present author reported the results of the chemical analyses of the major constituents of the oceanic salt collected from the western part of the North Pacific Ocean. These major constituents of the oceanic salt vary scarcely in their relative concentrations in sea water, while it cannot be over-looked that there are many minor constituents which, in spite of their smaller concentrations, have biological significances for the marine lives and vary widely in their concentrations according to depth and locality.

In the present report, the writer studied the vertical distributions of some minor elements in the region of the "Kurosio" (the Japan-Current), one of the largest oceanic current in the North Pacific Ocean

(1) This Bulletin, **14** (1939), 29, 55.

whieh runs north-eastwardly along the south-western coast of Japan, and obtained the some knowledge of the vertical structure of this current.

The samples of water for analyses were collected by M.S. "Ryôhû-maru".* The dates and the positions of sampling are as follows:

For the sampling of water Nansen's water-bottles were used and the measurement of water temperature, done at each position, down to the depth of 1,000 m., was carried out with Richter's reversing thermometers. Of each sample, determinations of hydrogen ion concentration and that of the amount of dissolved oxygen were made on board immediately after the collection, while the chlorinity determination and the chemical analyses of other elements were made later on land.

Table 1. The Dates and the Positions.

Date	Position		Date	Position	
Jan. 1939.	Lat. N	Long. E	Jan. 1939.	Lat. N	Long. E
16	33°24′	137°59′	23	32°30′	137°32′
20	32°35′	135°13′	24	31°37′	136°14′
21	31°35′	134°32′	24	31°22′	137°01′
21	30°49′	135°40′	24	32°00′	136°55′
21	30°37′	136°53′	25	32°08′	135°46′
21	31°00′	138°37′	25	32°29′	136°37′
22	32°06′	139°25′	25	32°33′	137°00′
23	31°48′	137°55′	25	32°21′	136°47′
23	32°35′	138°40′			

The Water Temperature. The average values of the water temperature at various depths are given in Table 2 and Fig. 1.

Table 2. The Water Temperature at Various Depths.

Depth (m.)	t°C.	Depth (m.)	t°C.
0	17.9	300— 400	8.9
25	18.0	400— 500	8.1
50	17.8	500— 600	7.6
100	17.6	600— 700	5.8
100—150	15.2	700— 800	4.6
150—200	14.6	800— 900	4.3
200—250	13.9	900—1000	3.2
250—300	11.0		

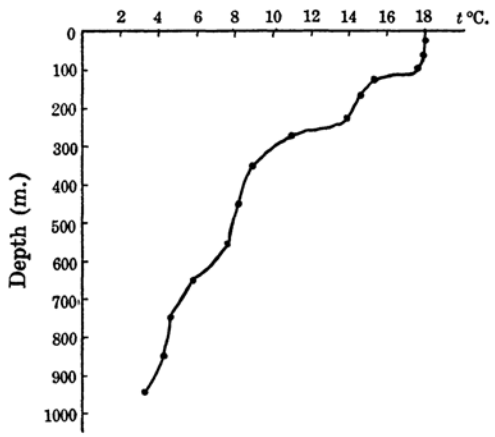

Fig. 1. The Vertical Variation of the Water Temperature.

* An observation ship of the Central Meteorological Observatory of Japan.

As seen in Table 2 and Fig. 1, the water temperature of the upper layer ranging from 0 to 100 m. is almost constant, and it suddenly falls in the next 50 m. Then it begins to decrease gradually down to the depth of 900–1000 m., where about 3°C. was recorded. It is notable that there is found the existence of a second layer of sudden decrease in temperature at the depth of 600–700 m.

The Chlorinity. The chlorinity was determined in the usual way. Table 3 and Fig. 2 give the mean vertical variation of the chlorinity, on whose relation to the vertical structure of the "Kurosio" will be briefly discussed in the following.

Table 3. The Chlorinity at Various Depths.

Depth (m.)	Cl ‰	Depth (m.)	Cl ‰
0	19.24	300– 400	19.03
25	19.23	400– 500	19.03
50	19.23	500– 600	19.01
100	19.22	600– 700	18.98
100–150	19.15	700– 800	19.01
150–200	19.14	800– 900	19.02
200–250	19.13	900–1000	19.06
250–300	19.07		

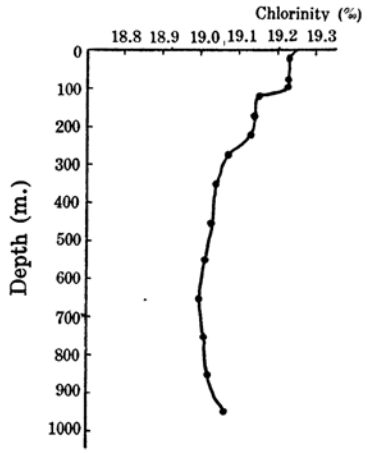

Fig. 2. The Vertical Variation of the Chlorinity.

The Temperature Salinity Diagram. The Vertical Structure of the "Kurosio". Needless to say, the vertical variation of elements in sea water is governed to a great degree by the vertical structure of the ocean, therefore it is necessary to draw a T–S diagram (Fig. 3) in order to investigate the vertical structure of the "Kurosio".

In the first place, we can see from this diagram that there is a thick surface water layer which is almost homogeneous and extends down to a depth of about 100 m. A marked discontinuity is noticeable between 100 and 150 m., followed by a layer down to about 600–700 m. with the gradual decrease in temperature and in salinity. The 100–150 m. layer, having a relatively higher chlorinity and temperature seems to form the center of the "Kurosio"; on the other hand, the 600–700 m. layer with relatively low salinity seems to consist of the subarctic intermediate water. Then it is very

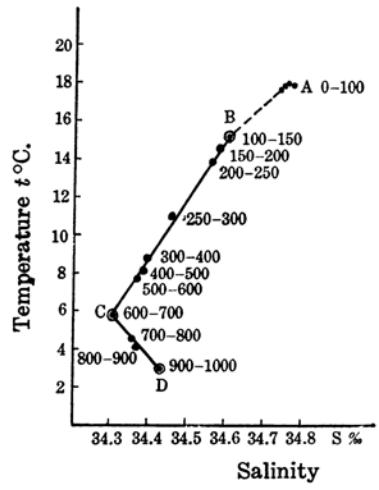

Fig. 3. The T–S Diagram.

likely that there occurs mixing of the two water masses of different character.

Below the 600–700 m. layer, the salinity gradually increases again; this increase is perhaps due to the mixing of two kinds of water masses, the subarctic intermidate water and the deep water.

Thus from the T-S diagram, we can distinguish four different water layers or strata in the vertical structure of the "Kurosio", namely, (A) the surface water, having both a higher temperature and a higher chlorinity, and its thickness being about 100 m.; (B) the main part of the "Kurosio" at about 100–150 m. below the surface and having a moderately high temperature and chlorinity (Cl‰ 19.15, t°C. 15.2); (C) the subarctic intermediate water, found at a depth of 600–700 m. and having a lower chlorinity (Cl‰ 18.98); and finally (D) the deep water.

The above result of the vertical structure of the "Kurosio" agrees on the whole with those obtained formerly by other oceanographers, however, it will be noteworthy that the existence of some characteristic features were made out in the author's present result.

The Density in situ. As the rate of the vertical stability mainly depends upon the density of water *in situ*, it is of interest to see the vertical change of the density in the "Kurosio" region.

In Table 4 and Fig. 4, the average values of σ_t at various depths are given, where σ_t is the (density -1) $\times$ 1,000 at temperature, t°C.

Table 4. The Vertical Variation of the Density.

Depth (m.)	σ_t	Depth (m.)	σ_t
0	25.13	300– 400	26.68
25	25.09	400– 500	26.78
50	25.13	500– 600	26.82
100	25.17	600– 700	27.05
100–150	25.65	700– 800	27.22
150–200	25.77	800– 900	27.27
200–250	25.90	900–1000	27.43
250–300	26.37		

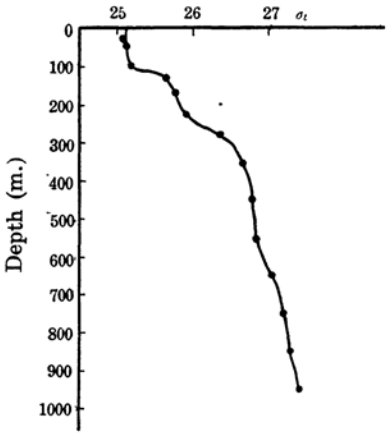

Fig. 4. The Vertical Variation of the Density *in situ*.

As seen in Table 4 and Fig. 4, we can recognize that the vertical stability of the "Kurosio" below 100 m. is so large that it hinders the vertical convection, while, the densities of the surface water down to 100 m. are practically the same, therefore the mixing of water allowed to take place easily.

Oxygen. The dissolved oxygen was determined by the Winkler's method by Dr. T. Yanagisawa immediately after the collection of the

sample. Table 5 and Fig. 5 give the result, which confirms the existence of a similar vertical structure of the "Kurosio" as mentioned in the foregoing paragraph.

Table 5. The Dissolved Oxygen in Sea Water.

Depth (m.)	Dissolved Oxygen (c.c./l.)	Saturation Percentage (%)	Depth (m.)	Dissolved Oxygen (c.c./l.)	Saturation Percentage (%)
0	5.17	93.2	300— 400	2.86	45.5
25	5.09	91.5	400— 500	2.75	43.4
50	5.06	91.1	500— 600	2.46	39.0
100	4.93	88.3	600— 700	2.07	28.5
100 — 150	4.34	74.8	700— 800	1.73	23.9
150 — 200	3.99	68.2	800— 900	1.65	22.6
200 — 250	3.80	58.8	900—1000	1.61	20.3
250 — 300	3.40	54.9			

It is a well known fact that there is found a peculiar intermediate minimum in the vertical variation of oxygen in the open sea. Thus in the Atlantic, it often occurs at the depth of several hundred metres, while in the eastern part of the Pacific, as has been reported by E. G. Moberg,[2] the amount of oxygen decreases from the surface with a nearly complete saturation towards the depth of 700 m., where it attains its minimum of less than about 1 ml./l.

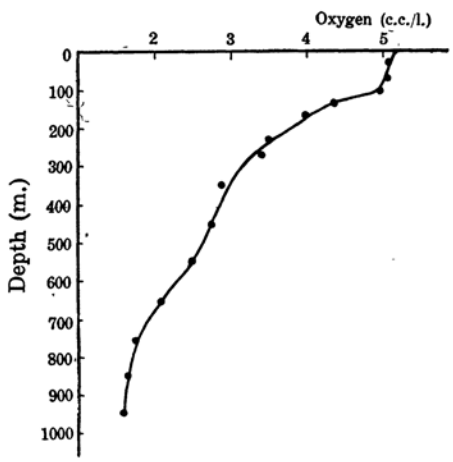

Fig. 5. The Vertical Variation of Oxygen (c.c./l.)

H. Wattenberg[3] ascribes recently the actual cause of this intermediate oxygen minimum to the biological actions, considering that the biological consumption of oxygen decreases rapidly with increasing depth. He pointed also an intimate relation between the maximum of phosphate and the minimum of oxygen in which he states that the maximum of phosphate is usually found in the water layer below the intermediate oxygen minimum.

It is also well known that besides this intermediate minimum, there often occurs a maximum in oxygen content near the surface. In the present case, down to 1,000 m., so far as the range explored is concerned, neither minimum nor maximum in the amount of dissolved oxygen could be found. According to E. G. Moberg, the eastern Pacific-water contains

(2) E. G. Moberg, *Bull. Nat. Research Council*, **85** (1932), 95.
(3) H. Wattenberg, *Ann. Hydrographie*, **67** (1939), 257.

less oxygen than the Atlantic water. It is interesting to compare the content of oxygen in the western Pacific with other oceans. It appears that the oxygen content in the "Kurosio" is even less than in the eastern part of the Pacific. Further quantitative study will be done in future.

The Hydrogen Ion Concentration. The hydrogen ion concentration of the sea water determined on board colorimetrically using cresol red and thymol blue as indicators. As in the cases of other oceans, the pH is about 8.2_5 at the surface and decreases gradually with the depth (Table 6 and Fig. 6).

Table 6. The Vertical Variation of pH.

Depth (m.)	pH	Depth (m.)	pH
0	8.25	300— 400	8.00
25	8.25	400— 500	7.95
50	8.25	500— 600	7.90
100	8.25	600— 700	7.81
100—150	8.20	700— 800	7.80
150—200	8.19	800— 900	7.74
200—250	8.14	900—1000	7.78
250—300	8.12		

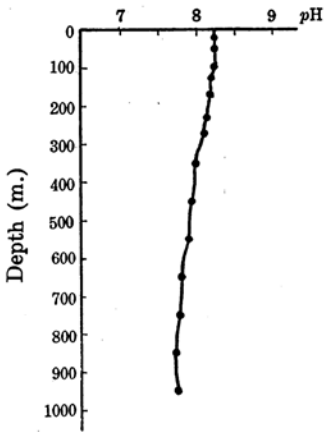

Fig. 6. The Vertical Variation of pH.

The constancy of pH values from the surface down to about 100 m. indicates the complete mixing of the upper water, which brings the sea water in equilibrium with carbon dioxide in the air.

Summary.

(1) The vertical variations of chlorinity, temperature, the oxygen content and the hydrogen ion concentration in the region of the "Kurosio" (the Japan-Current) were investigated.

(2) From the result above, the vertical structure of the "Kurosio" was discussed.

In conclusion, the author wishes to express his hearty thanks to Professor T. Okada, Director of the Central Meteorological Observatory of Japan, for his kind guidance and the permission of publishing this report. He is also indebted to Mr. H. Matui for the assistance of the work.

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