On Some Oceanographical Researches of the Sea-Water of Kurosiwo.

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With 7 tables and 9 figures.

Abstract.

The general features of the oceanographical conditions in the Kurosiwo-area are investigated on the basis of the charts constructed for the horizontal and vertical sections of the water mass in this region. Special attention is paid to the Oyasiwo-Undercurrent. Some detailed investigation is made on the results of the seasonal observations carried out on board the Sôyômaru, in the Kurosiwo-area in the vicinity of the Idu Islands. In § III, the distributions of temperature, specific gravity, water colour and transparency, the amounts of oxygen and CO_2 gas dissolved, and the PH and plankton content are described. Some relations among these quantities are pointed out. In these seasonal observations, the data were taken down to a depth of 1000^m–2000^m.

I. *Introduction.* Kurosiwo (the Japanese Current or, literally, the *Black Salt Current*) is usually regarded as a branch of the North Equatorial Current extended into the higher latitude. The oceanographical conditions of its surface layers were hitherto investigated on occasions. However, our knowledge regarding the water layer below the surface of Kurosiwo is still very obscure, since most of the previous observations were made only to the depth of at most three or four hundred metres. Recently, G. Wüst[1] carried out a systematic research in this respect compiling all the materials utilizable since the Challenger Expedition.

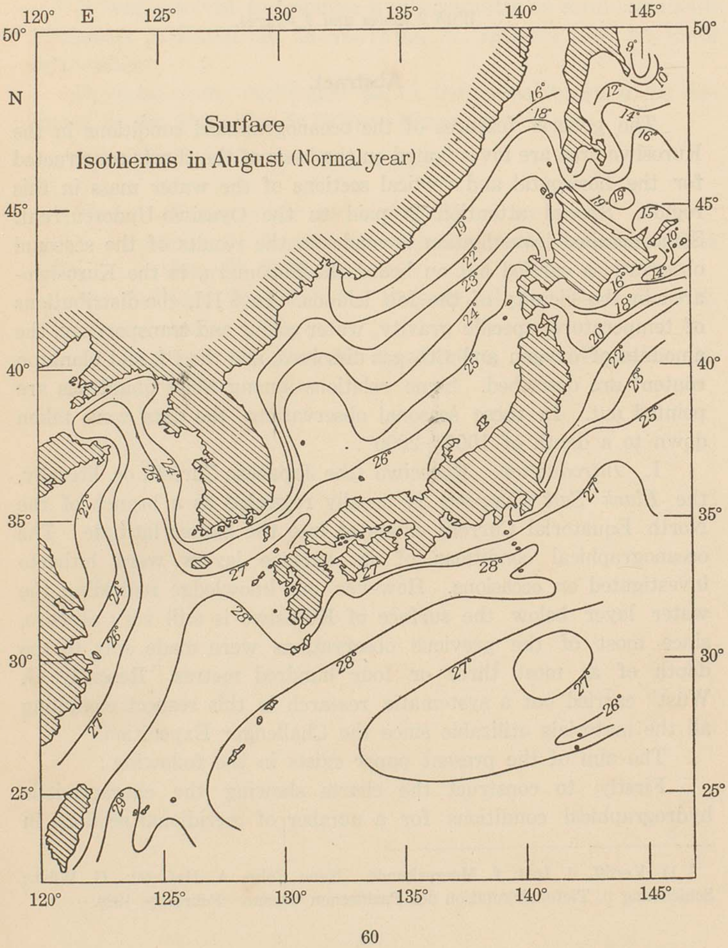
The aim of the present paper exists in the following:

Firstly, to construct the charts showing the characteristic hydrographical conditions for a number of meridional sections in

1) Veröff. d. Inst. f. Meereskunde. Neue Folge A, Heft 20. G. Wüst: Schichtung u. Tiefenzirkulation des Pazifischen Ozeans. February, 1929.

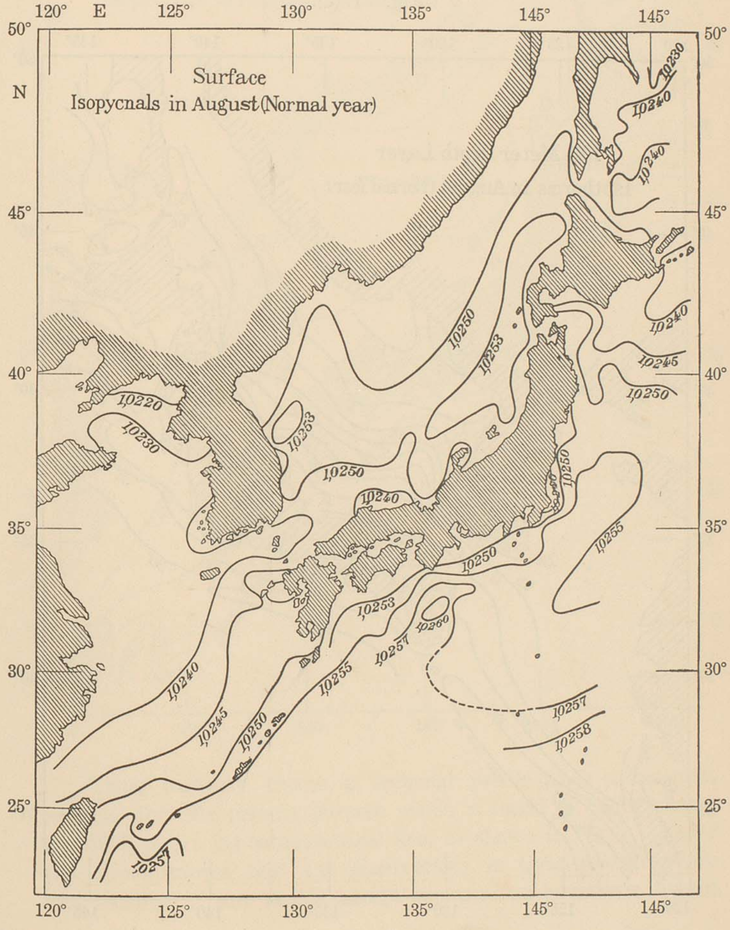
the domains of Kurosiwo and Oyasiwo (Cold Current) respectively; secondly, to investigate the seasonal changes of the physical and chemical conditions of those areas down to a considerable depth; thirdly, to discuss Wüst's theory in its details and thus to bring the nature of the peculiar phenomena of Kurosiwo along our

Fig. 1 (a).



Pacific coast under a broader light than ever. The materials were taken mainly from the "Quarterly Report of Oceanographical Investigation," published by the Imperial Fisheries Institute, Tôkyô.

Fig. 1 (b).



II. *Vertical Section along Kurosiwo.* Glancing over the oceanographical chart, Fig. 1, for August in the normal year, drawn by the present author, we can easily locate what we may call the principal axes of Kurosiwo and Oyasiwo from the general trends of the iso-lines.

Fig. 1 (c).

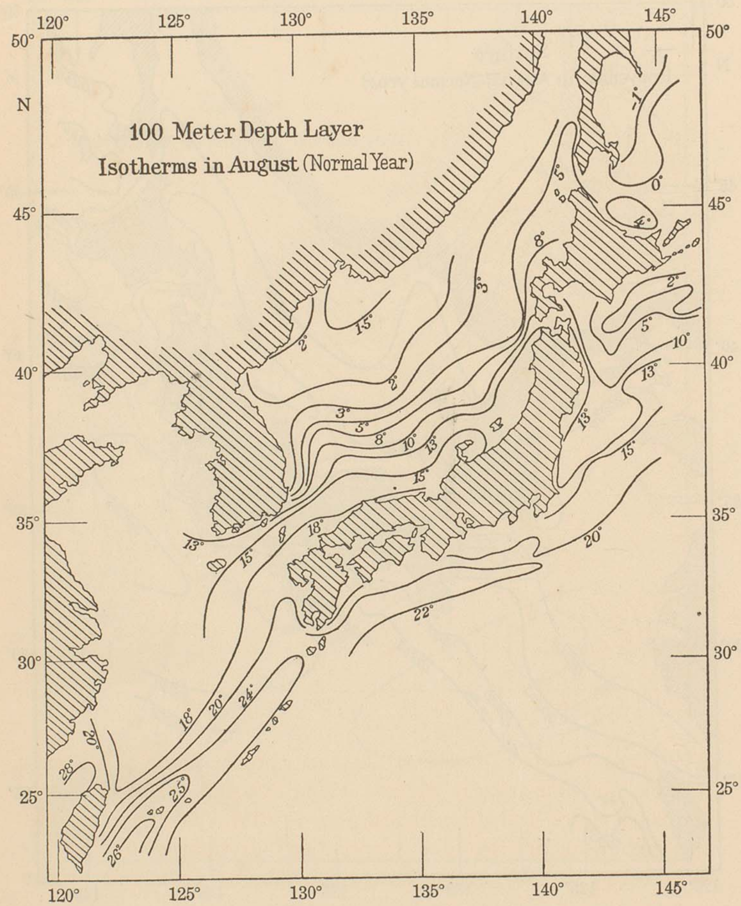
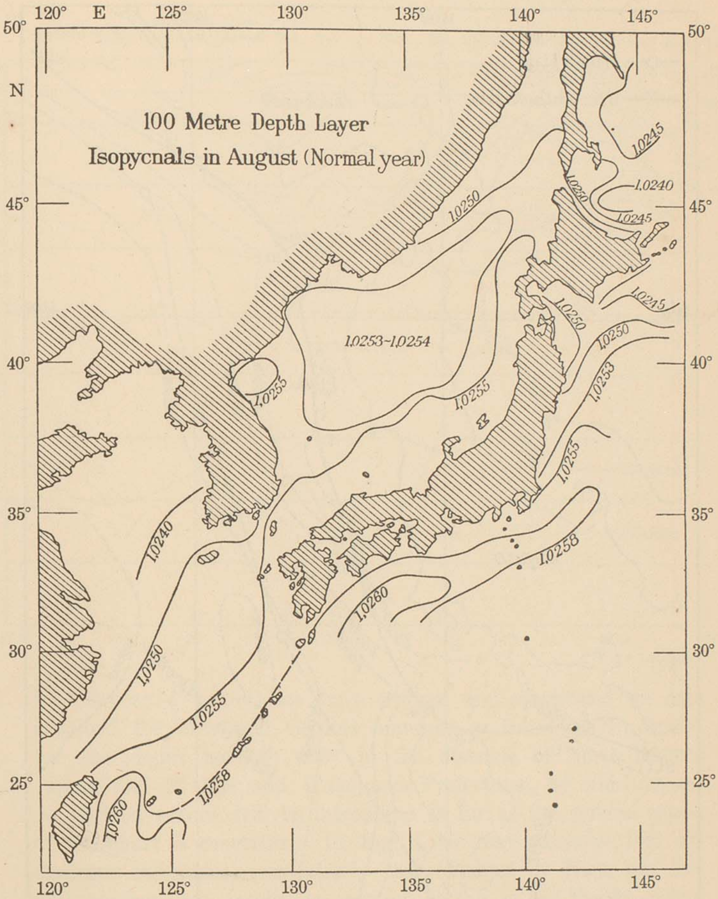
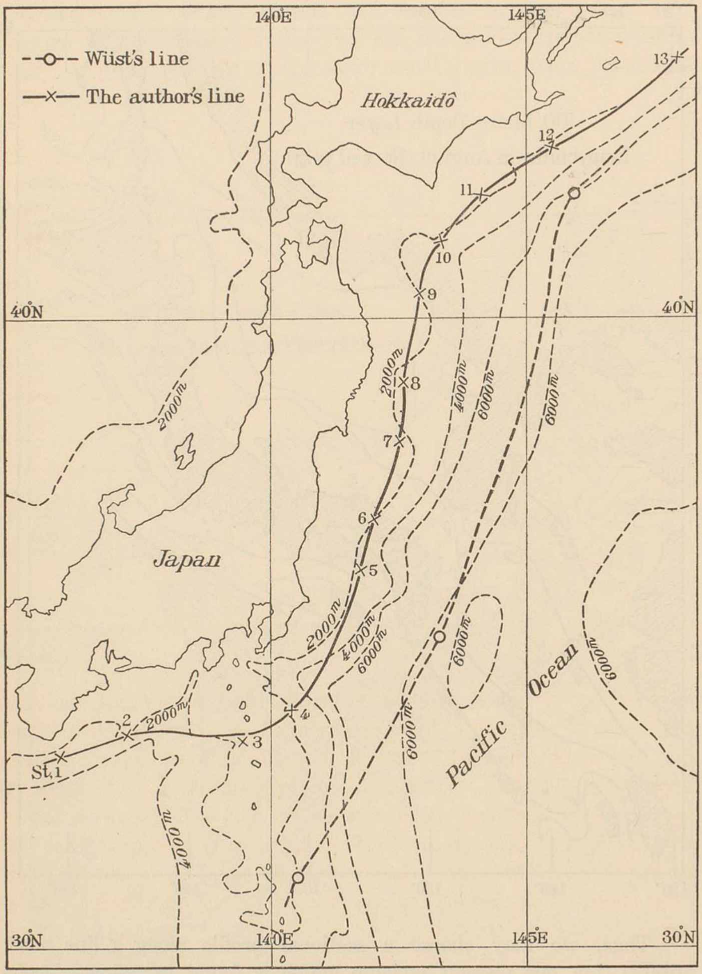


Fig. 1 (d).



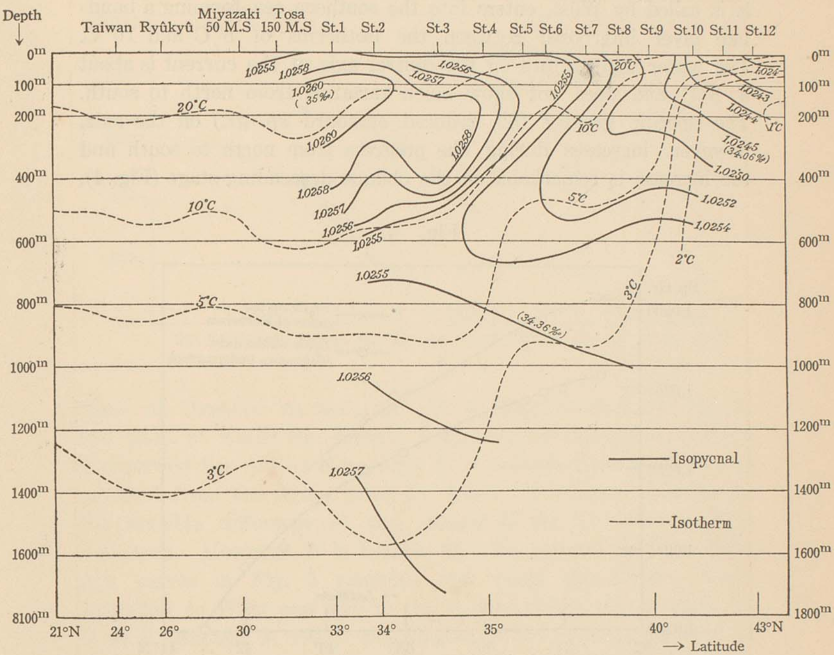
Thus, we may choose a sectional profile along a line most suitable for our present purpose which is found to follow closely the 2000 metre iso-bathymetrical line, as shown in Fig. 2. Under the circumstances that the observations in Oyasiwo-district are very scanty in any season except summer, we have been obliged

Fig. 2.



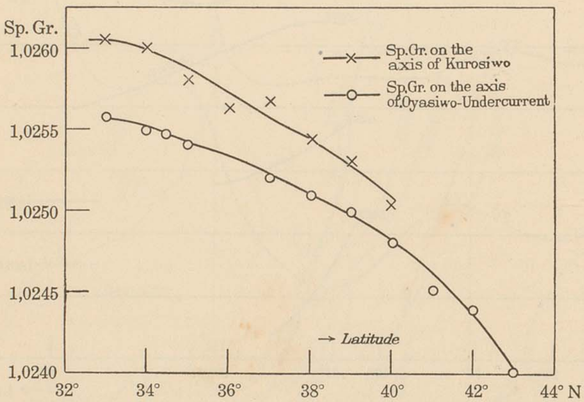
to be content with drawing the oceanographical chart in the above vertical section for August only, as seen in Fig. 3. It must be noted in this place that, availing ourselves of the fact mentioned

Fig. 3. Section of Kurosiwo in August (Normal year).



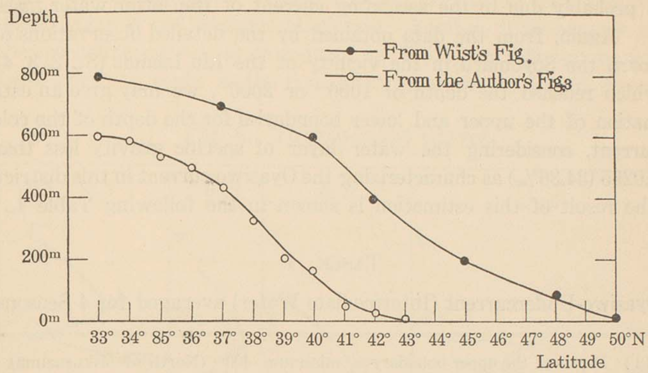
in Chapter 4 below, we have utilized and substituted the data obtained for May and October observed on board the Unyômaru for the depth beneath 400m in the districts of North Eastern Japan, and of Mie and Wakayama Prefectures, by which means no serious errors will be introduced as far as the general aspect of the chart is concerned. In Fig. 3, we may recognize that our diagram resembles very closely that obtained by Wüst, and this will confirm his results as correct, as far as our Pacific coastal area is in question. Thus, Oyasiwo, the cold northern current, begins to dive beneath the surface near St. 10 (41°–42° N) in the southern district of Hokkaidô, in August, and slides down along the oblique "Polar front" from the surface to the depth of 600m somewhere about St. 5 which lies 5° apart in latitude from the former. Then, it proceeds southwards, sinking slowly down to the depth of 700^{m}. Such an undercurrent, i.e., "Zwischenstrom", as it is called by Wüst, enters into the southern sea forming a band-like layer interposed between the isotherms of 5° C and 10° C. The water temperature on the central axis of the current is about 5°–8° C and does not show much variation from north to south. The specific gravity (S^{15}_{4}, reduced standard sp. gr.) on the axis, however, increases during the progress from north to south and the increase is remarkable in the oblique descending stage (Fig. 4).

Fig. 4.



The water layer above 400^{m} (subtropische Unterwasser, as it is called by Wüst) of the warm and highly-saline water of Kurosiwo is terminated in the Aomori offing near St. 9. The axis of the current is to be considered as following closely the isothermal line of 20° C. Moreover, Fig. 3 shows the existence of a highly warmed surface layer ("Deckschicht") with a comparatively low salinity, and also of the deep-water mass (usually beneath the 900^{m} depth under Kurosiwo ("Tiefenwasser") characterized by a high salinity and low temperature in a clear contrast with "Zwischenstrom". Fig. 4 represents the mode of decrease of the salinity with the march of Kurosiwo from south to north also that of the increase of the salinity with the creeping course of Oyasiwo from north to south. Again, plotting the depth of the cold current axis against the latitude as abscissa, for representing the descending

Fig. 5. The Descending stage of Oyasiwo.



stage of Oyasiwo current, we get a diagram shown in Fig. 5. The point at which the descent of the current beneath the surface is observed lies southwards about 6° in latitude apart from the one required from the figure given by Wüst. This seems to be due to the sensible difference of the position of the two sectional lines compared. However, it is notable that the general features of the two curves in Fig. 5 resemble each other very closely. Next, according to Wüst and also to the results of the survey made by H. M. S. Mansyû in 1925,[1] the tongue of the "Zwischenstrom" is shown to be stretched far southwards into the equatorial district, but in our case the influence of Oyasiwo-Undercurrent is already weakened at 33° N (Mie St. 2, Wakayama St. 1) and its boundary against the overlying Kurosiwo becomes obscure. The weak development of the undercurrent in our case is probably determined by some causes related with the bathymetrical features of the sea bottom. On the other hand, according to the observations of Mansyû, the influence of "Zwischenwasser" (minimum S) is recognized in Ryûkyû and Taiwan districts. This may probably be considered to be connected with the northern water mass coming round the Bonin Islands towards these districts, but not along the Pacific coast of our main land. Moreover, the cold area represented in the Oceanographical chart of Kurosiwo near Ryûkyû

1) The Hydrographical Bulletin, 4th Year, p. 576 and 646 (Japan).

and Taiwan, published by the Japanese Hydrographical Department,[1] is probably due to the ascending current of the latter water mass.

Again, from the data obtained by the detailed observations on board the Sôyômaru in the vicinity of the Idu Islands (St. 2, 3, 4), which reached the depth of 1000^m or 2000^m, we may give an estimation of the upper and lower boundaries for the depth of the cold current, considering the water layer of specific gravity less than 1.0255 (34.36‰) as characterizing the Oyasiwo current in this district. The result of this estimation is shown in the following Table 1.

TABLE 1.

Oyasiwo-Undercurrent (Intermediate Water) averaged for 4 Seasons.

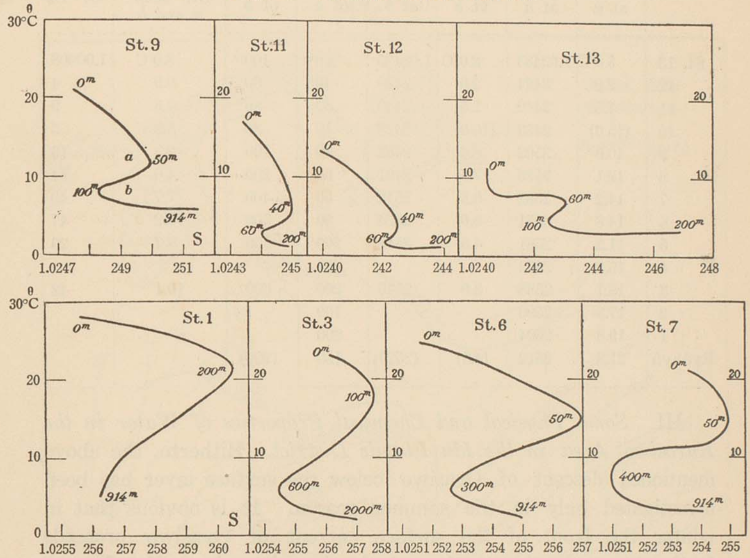
(i) Depth of the upper boundary...	minimum 400^m (North of Mikurazima) commonly 500^m (in the neighbourhood of Mikurazima) maximum 600^m (South Hatidyôzima)
(ii) Depth of the lower boundary...	$800^m - 900^m$ (North shallow, South deep)
(iii) The thickness of the layer......	$300^m \sim 400^m$
(iv) The position of the current axis.	nearly 600^m depth (South Hatidyôzima 700^m)
(v) Sp. gr. on the current axis......	maximum 1.02548 (South) minimum 1.02541 (North) generally very homogeneous; 1.02546

Studying the vertical distribution curves of temperature and salinity at each station, the results already deduced from Fig. 3 will be borne out more conspicuously. They indicate a state of Kathohaline (i.e., upper layer of low salinity, lower layer of high salinity) in the northern district of Aomori (St. 9–10), and one of Dicohaline (i.e., upper layer of high salinity, intermediate layer of low salinity, lower layer again of comparatively high salinity) in the southern district of St. 9. Combining this fact with the result obtained from Fig. 4 it seems that the water layer from St. 9 to St. 4 is relatively unstable so that the vertical circulation may be

1) The Hydrographical Bulletin, 6th Year, 1927, p. 18 and 7, figures represented.

vigorous in this district. It will, however, be understood easily from the investigation of the specific gravity *in situ* that the upper layer is not unstable absolutely. Further, if we arrange the thermo-haline curves, as introduced by Wüst, for different stations from north to south in the due order, as shown in Fig. 6, we can

Fig. 6. Thermo-haline Curves.



distinguish the characteristics of each sea-district more distinctly. At a glance on these characteristic curves we observe that the general tendency of the curve for the northern district to run from the left to lower right is changed into an opposite trend of the curve for the southern district, i.e., running from upper right to lower left. It is found also that the portion of the curve convex towards the temperature axis, i.e., the portion due to Oyasiwo-Undercurrent, is shifted from north to south regularly. It occurs to the present author that the position of the current axes (Kern) of Kurosiwo and Oyasiwo-Undercurrent can be determined from those thermo-haline curves by marking out the points such as are marked by *a* and *b* respectively in Fig. 6 and that this method is certainly a rational and the most convenient one. The following Table 2 shows the results calculated from the observations in August.

TABLE 2.

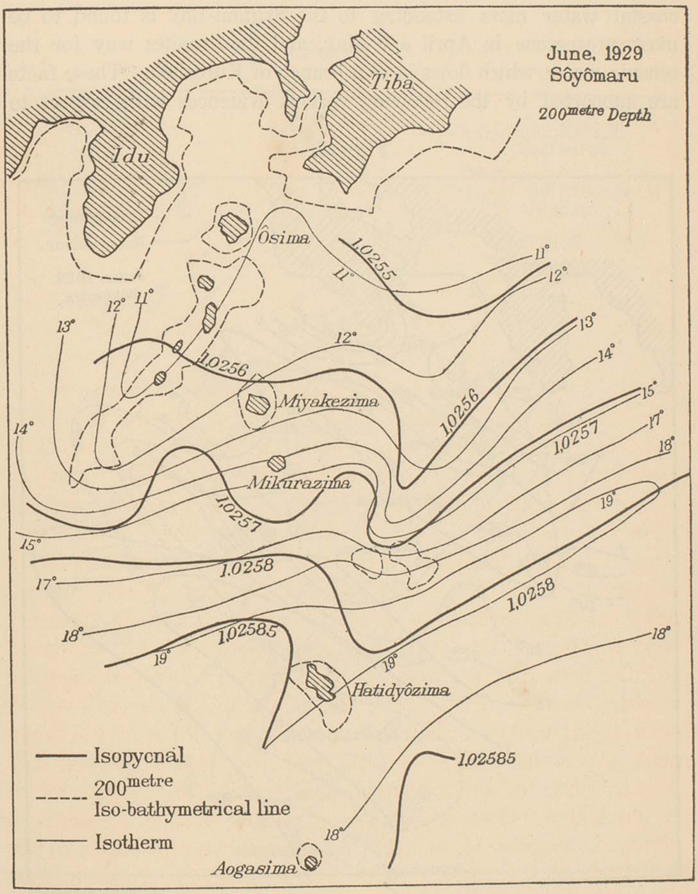
	θ Temp. at a	Sp. gr. at a	Temp. at b	Sp. gr. at b	Depth of a	Depth of b	$\theta_a-\theta_b$ Temp. Dif. betw. a and b	S_a-S_b
St. 13	5.0°C	1.02433	2.0°C	1.02425	60^m	100^m	3.0°C	1.00008
12	2.9	2424	2.0	2420	40	60	0.9	4
11	7.0	2449	2.5	2440	30	80	4.5	9
10	(15.0)	2433	(10.0)	2428	10	30	5.0	5
9	10.9	2502	8.6	2483	50	100	2.3	19
8	12.1	2525	7.5	2491	50	200	4.6	34
7	14.2	2552	6.5	2512	50	400	7.7	40
6	14.8	2571	5.6	2524	50	300	9.2	47
5	11.2	2561	4.5	2532	200	550	6.7	29
4	16.2	2579			200			
3	18.1	2588	8.0	2546	200	600	10.1	42
2	17.3	2596			100			
1	19.8	2604			200			
Ryûkyû	21.3	2612	(4.3)	(2529)	150	(900)		

III. *Some Physical and Chemical Properties of Water in the Kurosiwo Area in the Idu Islands District.* Hitherto, the above mentioned descent of Oyasiwo below the surface layer has been investigated only in the summer season. It is obvious that in winter the front of the surface current of Oyasiwo proceeds further towards the south and develops its sphere of influence. Thus, it becomes desirable for our next step to discuss the seasonal movement of the polar front as well as the vortices produced along the front surface. A detailed study on the points, however, must be reserved for some other time. For the present, we intend to give here only a provisional consideration on this problem by availing ourselves of a part of the data obtained by the detailed observations made on the occasion of the expedition of the Sôyô-maru in the Idu Islands district carried out in four seasons (i.e., August, 1928, November, 1928, February, 1929, May to June, 1929). As the author had an opportunity of making his own observations during the cruise of June, 1929, he was enabled to note down the full details of the necessary data on that occasion. It seems that no seasonal observations were hitherto made reaching to such a depth as 1000^{m} to 2000^{m} as in the present case. We wish, therefore, that our results may be verified by a future expedition.

(i) Water Temperature and Specific Gravity.

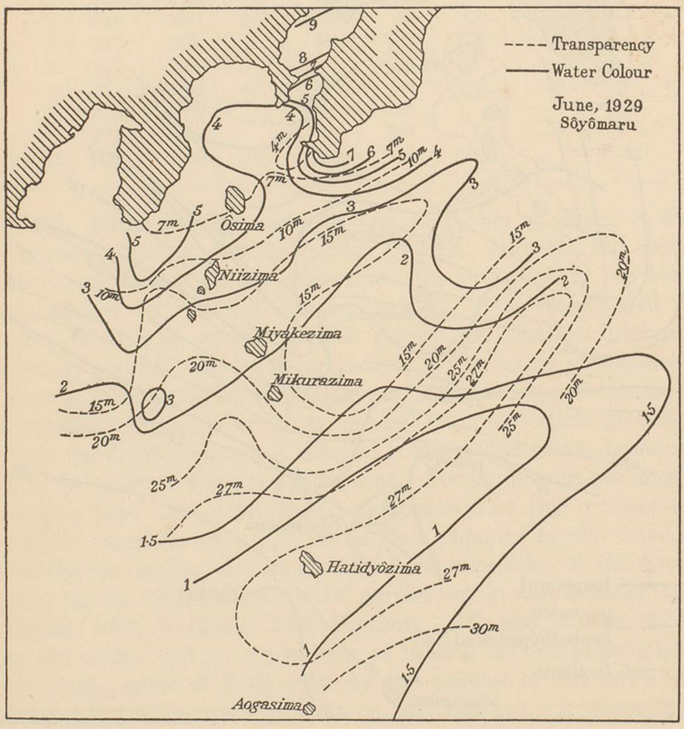
Firstly, the isotherms and isopycnals were drawn for each of the layers 0^{m}, 50^{m}, 100^{m}, 200^{m}, 400^{m}, 600^{m}, 800^{m}, 1000^{m}, in depth,

Fig. 7.



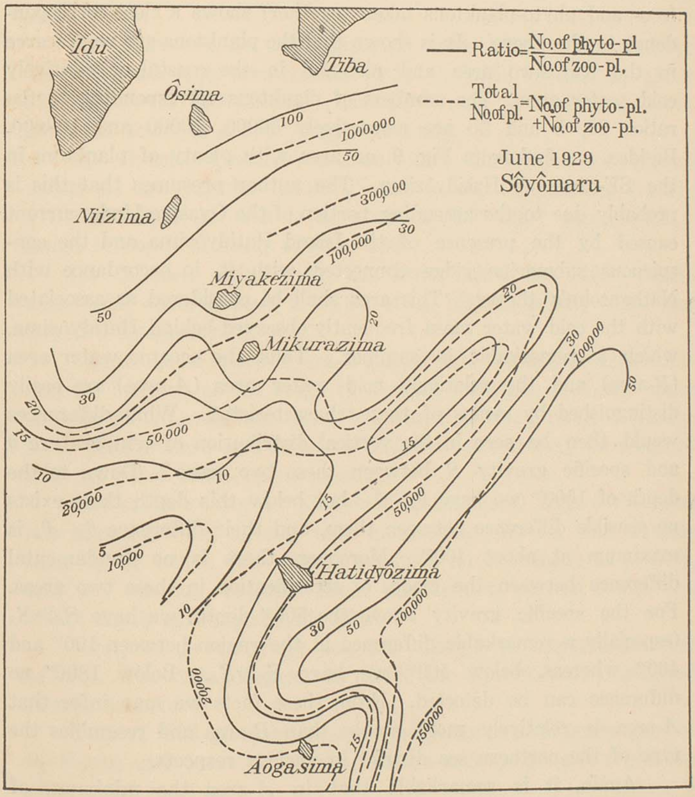
respectively. A representative example of those for the 200^m depth in early June, 1929 is shown in Fig. 7. Examining Fig. 7 and similar charts, we see that the axis of Kurosiwo lies always between Mikurazima and Hatidyôzima and that the seasonal growth and decay of Kurosiwo are limited mainly to the upper layers. On the other hand, a comparatively cold water mass mingled with the coastal water is seen to be invading the domain of Kurosiwo in a tongue-like form. Besides, another relatively cold coastal water mass extending to the Sagami-Bay is found to be most prosperous in April and May, and then makes way for the oceanic water which flows in as a branch of Kurosiwo. These facts are supported by the following various evidences with respect to

Fig. 8.



(a) the distribution of the total quantity of planktons (Fig. 9),
(b) the distribution of zoo- and phyto-planktons (Fig. 9),
(c) the iso-transparency curve (Fig 8),
(d) the lines connecting the points with equal numbers of water colour in Forel's scale (Fig. 8),
(e) the horizontal distribution of the dissolved CO_2 gas,
(f) the distribution of the percentage saturation of Oxygen gas, etc.

Fig. 9.



The general features of distributions represented in Fig. 8, Fig. 9 etc. coincide very well with Fig 7. If we examine the chart of distribution for the ratio of the number of phyto-planktons to that of zoo-planktons in Fig. 9, we find that the (20–30) line in this figure resembles very well the outline of the Kurosiwo area in Fig. 7. In other words, the quantity to zoo-planktons (Copepoda, Radioralia etc.) is relatively more abundant in the Kurosiwo area than in the colder area, and in the cold water area—almost all belonging to the coastal water area—the quantity of phyto-planktons (Chaetoseras, Rhizosolenia etc.) is richer than in the Kurosiwo area. The distribution of the total quantity of planktons (zoo- and phyto-planktons taken together) shows a close correspondence to the above. It is shown that the planktons are very scarce in the Kurosiwo area and plentiful in the coastal or relatively cold water area. The numbers of planktons corresponding to the ratios 20, 5 and 30 are respectively 50000, 10000 and 100000. Besides, we find from Fig. 9, an area with plenty of planktons in the SE-area off Hatidyôzima. The author presumes that this is probably due to the ascending portion of the Oyasiyo-Undercurrent caused by the presence of the Island Hatidyôzima and the conspicuous submarine ridge connected with it, in accordance with Nathansohn's theory. This area shall be considered as associated with the cold water mass frequently observed behind Hatidyôzima, which is remarkable in summer. Thus, the oceanic water area (*B*-area) and the relatively cold water area (*A*-area) are easily distinguished by means of these characteristics. What differences would then be seen in the vertical distribution of temperature θ and specific gravity S between these two areas? Down to the depth of 1000^m we have $\theta_B > \theta_A$, but below this depth there exists no sensible difference between them, and their difference $\theta_B - \theta_A$ is maximum at about 400^m. Moreover, there is no fundamental difference between the modes of stratification in these two areas. For the specific gravity above the 500^m depth, we have $S_B > S_A$ (especially a remarkable difference in the region between 100^m and 400^m whereas, below 500^m we have $S_B > S_A$. Below 1800^m no difference can be detected. From these facts we may infer that *A*-area is relatively more stable than *B*-area and resembles the type of the northern sea district in various respects.

Again, it is remarkable that in *A*-area the minimum of salinity is marked more sharply than in *B*-area, also that the phases of the maximum and minimum of salinity in *A*-area are sensibly shifted towards the depth compared to *B*-area.

The surface layer in which the salinity is diluted by the influences of atmospheric precipitations has a thickness of about 100^m and shows very high temperature down to 100^m almost homogeneously. From the distribution of the specific gravity it is considered plausible to take the thickness of Kurosiwo at about 200^m including the above surface layer.

In short, the stratification of water in the domain of Kurosiwo in the Idu Islands district may be largely classified into the following three parts:

(1) Kurosiwo, an upper layer of water with a high salinity (34.70‰) and high temperature (>15° C) with its axis at about 150^m depth (or 100^m depth). This layer may be considered to be extended down to a 200^m depth generally.

(2) Oyasiwo-Undercurrent, an intermediate layer with a comparatively low salinity (34.30‰) and a low temperature (nearly 8° C), of which the axis is at about a 500^m–600^m depth with a range in depth of from 400^m to 900^m.

(3) A deep water layer, the layer below the 1000^m depth, with cold water (about 2°–3° C) of a higher salinity than the Oyasiwo-Undercurrent.

Besides these three layers, a discontinuity layer (Sprungschicht) may be inserted as the stage of a rapid transition from the upper layer to the intermediate one. However, this being really a mixing layer of Kurosiwo and Oyasiwo-Undercurrent, it may be assigned with no other independent meaning.

The surface layer of Kurosiwo (Deckschicht) with a thickness less than 100^m has already been mentioned. As for the deepest layer lying below [(3) above], we have no knowledge at present, and we can say nothing about the bottom current under the 3000^m depth as imagined by Wüst.

Next, let us study the seasonal change of temperature and salinity. For this purpose we divide the district into *A*-area and *B*-area as before.

Table 3 will give the average temperature and specific gravity in *B*-area and Table 4 the temperature and sp. gr. at a representative point in *A*-area.

TABLE 3.

Averaged on EW Line South of Mikurazima (Kurosiwo Area: *B*-area).

Season \ Depth	0m	25m	50m	100m	200m	400m	600m	800m	1000m	1500m	1800m	2000m
Winter ...	16.8°C 2590	17.0 2590	16.9 2588	15.7 2582	13.1 2571	8.7 2558	5.6 2554	5.0 2558	4.4 2561	3.0 2557	2.7 2565	2.5 2572
Spring ...	23.2 2566	22.4 2567	21.2 2574	18.3 2575	14.6 2569	10.2 2555	7.8 2547	5.8 2546	5.2 2549			
Summer...	27.5 2538	26.9 2555	25.8 2568	21.9 2568	15.1 2567	9.3 2561	6.7 2548	4.9 2551	4.1 2553			
Autumn...	24.6 2555	24.7 2556	24.6 2558	22.0 2578	16.8 2577	10.7 2555	8.0 2546	6.6 2553	5.1 2560			
Mean	23.0 2562	22.8 2567	22.1 2572	19.5 2576	14.9 2571	9.7 2557	7.0 2549	5.6 2552	4.7 2556			
Amplitude	10.7 52	9.9 35	8.9 30	6.3 14	3.7 10	2.0 6	2.4 8	1.7 12	1.1 12			

upper row......water temperature (°C); lower row......specific gravity S^{15}_{4} (2588 means 1.02588).

TABLE 4.

30 Miles SSE off Ôsima (A Representative Point of *A*-area).

Month \ Depth	0m	25m	50m	100m	200m	400m	600m	800m	1000m	1800m
February	15.1 2583	15.1 2586	14.7 2580	14.6 2559	12.3 2572	7.3 2547	5.1 2554	4.4 2554	3.5 2554	
June	18.6 2565	17.4 2572	16.4 2573	14.6 2571	10.5 2556	7.1 2546	5.6 2550	4.1 2554	3.4 2558	
August	26.4 2467	24.2 2529	21.9 2554	16.0 2564	12.8 2559	7.6 2546	5.1 2546	4.0 2561	3.4 2561	
November ...	22.4 2547	21.5 2558	21.0 2558	16.7 2572	11.2 2562	6.7 2554	5.0 2553	4.2 2559	3.3 2565	2.5 2572
Mean	20.6 2541	19.6 2561	18.5 2567	15.5 2567	11.7 2562	7.2 2548	5.2 2551	4.0 2557	3.4 2560	
Amplitude ...	13.3 116	9.1 57	7.2 26	2.1 13	2.3 16	0.9 8	0.6 8	0.4 7	0.2 11	

We remark from Table 3 that the depth of the maximum of temperature depends upon the time of year, i.e. the maximum is met with in middle August at 0^m, in early September at the 100^m depth, in November at a 200^m depth and at last in December below the 400^m depth. Moreover, it is remarkable that a secondary minimum of temperature appears from the 400^m depth on and thus a half-yearly periodic change of temperature is found with the two maxima in June and December. The corresponding secondary minimum in the sea district near St. 6, i.e. in the northern region, appears in July under the 200^m depth, and near St. 8 is met with already at the 50^m depth between July and August. The author considers that the origin of this minimum is probably due to the growth of the intensity of Oyasiwo-Undercurrent in summer. The confirmation of this interesting problem is, however, left for a future investigation.

According to Table 3, the seasonal variation of specific gravity from the 0^m to the 200^m depth takes a similar form, namely, a minimum in summer and a maximum in winter. However, below the 200^m depth, on account of the smallness of the amplitude of variation, it is difficult to detect the seasonal change of the specific gravity distinctly. On the whole, it seems to us that a similar minimum exists between spring and summer and a maximum in winter. Associating this with the fact that in the sea district off Hukusima (near St. 6) the minimum at the surface occurs in early May while it is shifted to middle May at a 300^m depth, it may be imagined that the minimum presented in early summer under the 400^m depth at St. 3 (Idu Islands district) has its origin in the influence of the growth of the northern Oyasiwo-Undercurrent.

The position of the minimum of the specific gravity in the Oyasiwo-Undercurrent is generally at 600^m–700^m throughout the year, and lies deeper in spring and summer, shallower in autumn and winter.

Summarizing the above results we have:

In the Kurosiwo-area (*B*-area)
(Idu Islands district)

above a 200^m depth:
- temperature: $\theta_{\text{summer}} > \theta_{\text{autumn}} > \theta_{\text{spring}} > \theta_{\text{winter}}$
- salinity: $S_{\text{winter}} > S_{\text{spring}} > S_{\text{autumn}} > S_{\text{summer}}$

below a 200^m depth:
- temperature: $\theta_{\text{autumn}} > \theta_{\text{spring}} > \theta_{\text{summer}} > \theta_{\text{winter}}$
- salinity: $S_{\text{winter}} > S_{\text{summer}} > S_{\text{autmun}} > S_{\text{spring (?)}}$

Further, if we draw the thermo-haline curves for each season from Table 3, we can see at once that, contrary to the winter curve, resembling to the southern type, the summer curve represents a rather northern type and the curves for spring and autumn are intermediate to the above two, while resembling each other.

(ii) Water Colour and Transparency.

The water colour is of higher numbers in Forel's scale and the transparency is of low values, in the spring season (April, May and June) compared with the summer season (July, August and September). Moreover clear colour and good transparency are conspicuous in *B*-area, while the opposite is the case in *A*-area, as seen from Fig. 8. On the whole, in the Kurosiwo area, at the time of early summer, the water colour is 1–2 (in Forel's scale) and the transparency is above (15^m–20^m), the transparency being given by the ultimate visible depth of a white disc $\frac{10^m}{33^m}$ in diameter.

(iii) Dissolved Quantity of Oxygen Gas.

Seasonal variation of the dissolved quantity of oxygen measured by Winkler's method shows a maximum in winter down to a 200^m depth as shown in Table 5, and below the 200^m depth the maximum is displaced from spring to summer.

TABLE 5.

Dissolved Oxygen c. c./litre.

Depth \ Season	Winter	Spring	Summer	Autumn	Mean	Amplitude
0^m......	5.29	4.81	4.68	4.78	4.89	0.61
25^m......	5.30	4.80	4.66	4.64	4.85	0.66
50^m......	5.21	4.71	4.82	4.42	4.79	0.79
100^m......	4.93	4.44	4.50	3.97	4.46	0.96
200^m......	4.07	4.21	4.31	3.52	4.03	0.79
400^m......	3.08	3.55	3.63	2.96	3.31	0.67
600^m......	2.17	2.95	2.71	2.15	2.50	0.80
800^m......	—	2.45	2.05	—	2.25	—
1000^m......	1.74	2.06	—	1.52	1.77	—

The minimum is in summer at the surface and its phase lags gradually towards autumn with the increase of the depth. The averaged value throughout the vertical column from the 200^m depth to the surface is above 4 c.c./litre. Since the dissolved quantity of oxygen is mainly determined by the water temperature, the above mentioned maximum and minimum can be said to coincide well with the lag of the maximum and minimum of the water temperature (compare (i)).

The rate of decrease of the dissolved oxygen with the increase of the depth has its maximum at a 50^m–100^m depth, and then it decreases slowly. Comparing this curve with the curve of the rate of decrease of the water temperature in the Kurosiwo area, we find a remarkable resemblance between them. Therefore, the water temperature-oxygen curve has a specific meaning characterizing each district. Next, examining the percentage saturation of the dissolved oxygen in the water column from 0^m to 50^m we have:

Feb. 90.9%, June 90.6%, Aug. 100%, Nov. 91.4%, Annual mean 93.2%.

Thus, perfect saturation occurs in August and the deficiency of saturation is maximum in June (9.4%). The difference of the percentage saturation due to locality amounts 17.5–19.5%. The value of the percentage saturation is remarkably great in the Kurosiwo area and always above the mean value, while in *A*-area the value is always below the mean value.

It is interesting to observe that the percentage saturation with oxygen is almost exclusively determined by the temperature and the effect of photo-synthesis by phytoplanktons is not conspicuous, since if the latter effect be predominant, we may expect that a greater saturation will be associated with a rich content of these plankton i.e. with the low temperature.

(iv) Dissolved quantity of CO_2 Gas (February and November observations).

The dissolved quantity of CO_2 gas is more abundant in winter for all depths than in autumn, as shown in Table 6. Namely, the alkalinity is stronger in winter than in autumn. In particular, the difference is remarkable in the domain of warm water above the 400^m depth. This might have been expected, since the salinity, the main factor determining the alkalinity, is notable in the layer above the 400^m depth.

TABLE 6.

Dissolved CO_2 Gas c. c./litre.

Month / Depth	Feb.	Nov.	Mean	Diff.	Feb. Max.	Feb. Min.	Feb. Ampl.	Nov. Max.	Nov. Min.	Nov. Ampl.
0^m	24.92	24.12	24.52	+0.80	25.02	24.65	37	24.41	23.87	54
100^m	25.18	24.79	24.98	+0.39						
200^m	25.05	24.77	24.91	+0.27	25.18	24.97	21	25.33	24.41	92
400^m	25.35	24.95	25.15	+0.40	25.66	25.13	53	25.87	24.25	162
600^m	25.68	25.67	25.68	+0.01	25.92	25.50	42	25.98	25.50	48
800^m	26.19	26.14	26.17	+0.05	26.51	25.92	59			
1000^m	26.46	26.00	26.23	+0.46	26.93	26.14	79	26.63	25.44	119
1500^m	26.44	26.96	26.70	−0.52	26.72	26.08	64			
1800^m	26.88	25.95	26.42	+0.93				26.44	25.28	116
2000^m	26.95		(26.95)							

The alkalinity increases rapidly to the depth 1000^m from the surface and, below this depth, it is almost constant. In other words, on entering into the deep water area the alkalinity is almost homogeneous.

When we examine the charts of the regional distribution of dissolved CO_2 gas in these two seasons, it is found rich in the *B*-area (warm and salty) and relatively poor in the *A*-area (cold and fresh), as might be expected.

It should be remarked that in Ensyûnada (near St. 2) the dissolved CO_2 gas in winter is abundant in the open sea and poor in the coastal area, but in autumn the contrary is the case (i.e. poor in the open sea, rich in the coastal area). This may probably be due to the influence of coastal water accumulated near the coast of "Ensyûnada" by the autumnal rain discharged from Tenryûgawa etc. Further discussion of this will be left for a future study.

(v) PH. The measurement of the hydrogen ion concentration by the colour comparison method (indicator: phenolphtaleine) was carried out only in the cruise of Nov., 1928 (see Table 7).

TABLE 7. PH.

Depth	Mean
0^m	8.30
25^m	8.30
50^m	8.27
100^m	8.16
200^m	7.95
400^m	<7.86

By the present method the water under the 400^m depth was found colourless. The values of PH. here found are greater than those previously obtained in June, 1918, over the Japan Sea,[1] and, especially, their difference is maximum at the depth of 50^m–100^m. This may be well accounted for by referring to the fundamental difference between the Japan Sea and the Pacific Ocean as characterized by the difference in the mode of decrease of the temperature with respect to depth in these two sea districts.

VI. *Concluding Remark.* From the above, it will be seen that the sea water in the domain of Kurosiwo may generally be classified into three water-layers and that for the investigation of Kurosiwo current as a whole it is necessary to extend the observation at least down to a 400^m depth.

For a theoretical consideration regarding the mode of stratification of sea water as is here concerned, the paper by A. Defant, entitled "Stabile Lagerung ozeanischer Wasserkörper und dazugehörige Stromsystem." (Veröff. Inst. Meereskunde, Univ. Berlin. Neue Folge, A, Heft 19) may be especially referred to.

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1) Annotation of the Oceanographical Research, the Imperial Fisheries Institute, Vol. I, No. 1, p. 6.