

29

41

Hydrographical Investigations in the Seas  
Adjacent to Wakasa Bay.

By M. UDA.

Reprinted from RECORDS OF OCEANOGRAPHIC  
WORKS IN JAPAN, Vol. IV, No. 1, June 1932.

## Hydrographical Investigations in the Seas Adjacent to Wakasa Bay

By Mititaka UDA,

The Imperial Fisheries Experimental Station.

(With 5 Tables, 21 Figures in Text and 1 Plate)

### Abstract.

In the present paper is investigated the system of currents prevailing in the seas adjacent to Wakasa Bay. This is done first indirectly from the results of simultaneous observations of the hydrographical data which were obtained in mid July, 1930, by the collaboration of four research ships. Several distinct water-masses are found, peculiar to these sea-districts, from the horizontal and vertical distribution of the observed data. Also the currents off the Bay were computed from Bjerknes's theory of circulation.

Next, in order to measure the currents directly, a number of current-drags were liberated from different points in the Bay and pursued by the simultaneous cooperation of the four research ships during 5 days. From the result of these observations a bird's eye view was constructed of the tracks of the surface current.

Thus, the characteristics of the large anticyclonic system of vortical currents induced by the Tusima Current in Wakasa Bay, were revealed more clearly than ever.

Moreover, surface drift-bottles were put out, 740 in number, in the inside and outside of the Bay. Studying their recovery reports (percentage of recovery 31.1%) we were able to form a general idea regarding the later course of the Tusima Current taken after its passage along the outside of Wakasa Bay and, moreover, we have ascertained that the Tusima Current was especially prosperous at the time of our observation.

### I. Introduction.

Wakasa Bay, well known for prosperous fisheries, is a large bay, with a width, measured from its mouth to its land end, of 20 miles and a frontage of 38 miles, facing the Japan Sea towards the N. However, no systematic hydrographical researches have hitherto been carried out.

From the 11th to the 17th of July, 1930, the research ship Sôyômaru of the Imp. Fish. Expt. St., in cooperation with the Sôwamaru of the Kyôto Fish. Inst., the Tazimamaru of the

Hyôgo Fish. St. and the Nisyûmaru of the Hukui Fish. St. was engaged in the investigation of the seas adjacent to Wakasa Bay. The oceanographical cross observations were made on the 11th, simultaneously. The stations of observation are indicated in Fig. 1. As for the details of the materials the readers are referred to the Semiannual Report of the Oceanographical Investigation No. 47, published by the Imp. Fish. Expt. St.<sup>1)</sup>

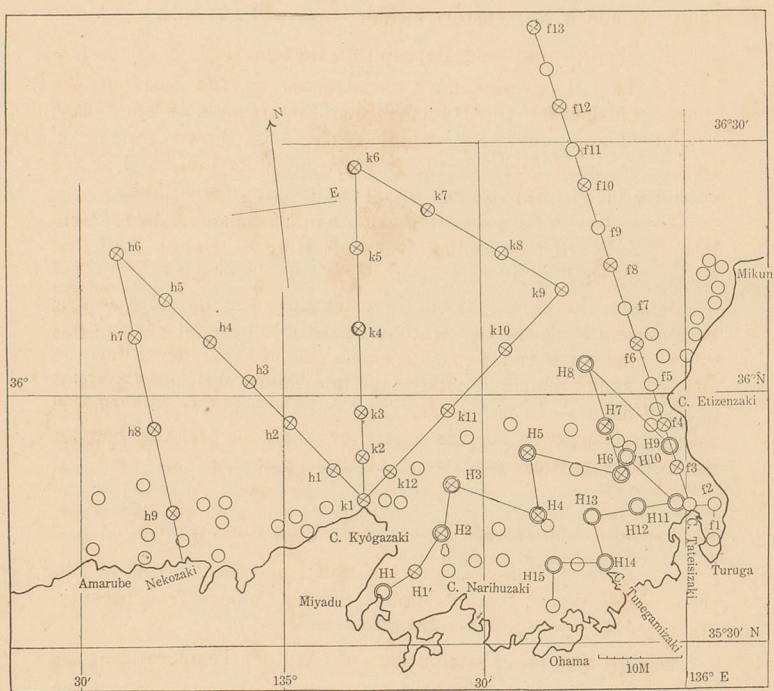


Fig. 1. Oceanographic Stations  
1930, July 11-16th.

- h .... Hyôgo Fish. Expt. St.      H .... The Imperial Fish. Expt. St.  
k .... Kyôto      "      "      f .... Hukui      "      "      "  
○ Sts. observed  
⊗ Sts. where drift-bottles put out  
⊙ Sts. where plankton-net hauled in

## II. Conditions.

### (i) Meteorological Conditions.

On the 11th of July, it was rainy due to the influence of two atmospheric depressions in the northern quarters and the sea was getting a little rough. Before noon of the 12th, it rained heavily and a westerly wind was observed as on the day before. The days from the 13th to the 16th were blessed with fine weather, calm sea and a soft easterly wind.

### (ii) Topography and Deposits of Bottom.

An isobathymetric chart, constructed on the basis of the chart published by the Hydrographic Department of our Navy, by introducing our new sounding data, is shown in Fig. 2. Depths in most parts of the Bay are below 200 m., and at the entrance of the Bay we see a 300 m. isobathymetric line.

Here it is to be noticed that a prominent bank called "Gen-tatu-no-Se" exists 20 miles west of Mikumi, Hukui Pref., of which the shallowest part is only of 50 m. in depth.<sup>2)</sup>

Within the extent of our investigation, the deposits of the bottom below the 200 m. depth are mostly some kind of clay-like green mud and the deposits above the 200 m. depth are in general, sandy-mud and muddy-sand intermixed with some remains of shell-fishes. In particular, near C. Etizenzaki and C. Tateisizaki the quantity of sand is relatively abundant, probably because the bottom currents are strong at these places.

## III. Indirect Method of Surveying the Currents.

(i) Several Water-Masses inferred from the Horizontal Distribution of Water Temp., Salinity, Water Colour, Transparency, Dissolved Oxygen and Plankton.

(a) Horizontal Distribution of Water Temperature and Salinity.

The distributions of water temperature and salinity at 0, 10, 50, 100, 200 m. depths are shown in Figs. 3 a, b, c, d, e respectively. Owing to the effect of solar radiation on land, the coastal water is relatively warm. Its salinity is naturally low. The further we recede from the coast to the sea off the Bay, the colder and saltier it becomes. On account of this circumstance it is difficult



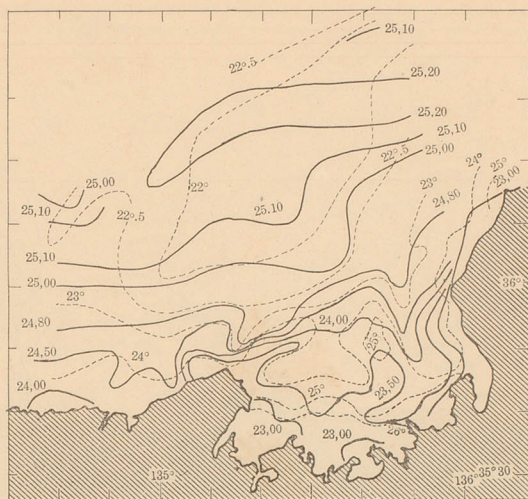
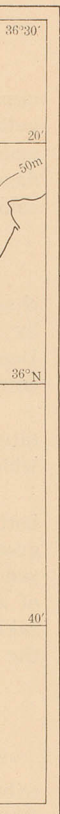


Fig. 3 a. Surface Temp. and Sp. Gr.  $\sigma_4^{15}$   
(1930, Mid July)

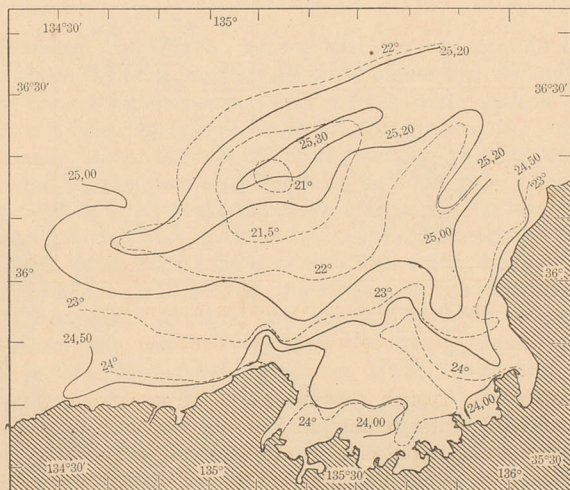


Fig. 3 b. Temp. and Sp. Gr.  $\sigma_4^{15}$  (10 m. Depth)  
(1930, Mid July)

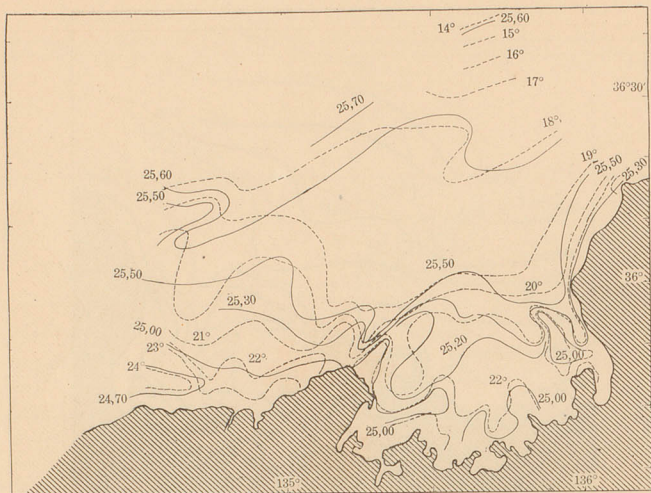


Fig. 3 c. Temp. and Sp. Gr. (50 m. Depth)  
(1930, Mid July)

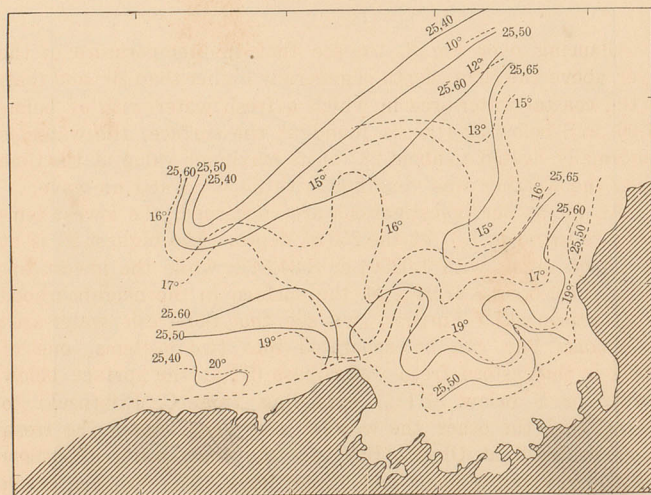


Fig. 3 d. Temp. and Sp. Gr. (100 m. Depth)  
(1930, Mid July)

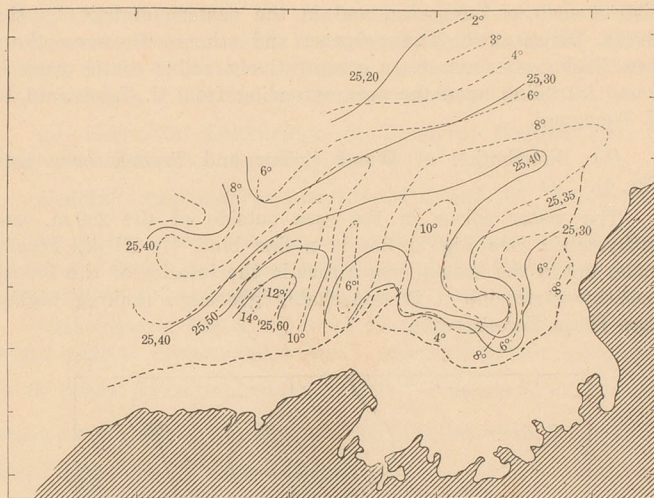


Fig. 3 e. Temp. and Sp. Gr. (200 m, Depth)  
(1930, Mid July)

Glancing over Fig. 3, we see that the temperature of the layer above the 50 m. depth is generally higher than  $20^{\circ}$  and that, in the coastal water-area in which a fresh water with  $\sigma_4^{15}$  below 24.00 or S below 32.41‰ is found at the surface, the water is abnormally heated to about  $28^{\circ}$  at its maximum value at the time when the weather was very fine with no wind and no wave.

As far as our investigations are concerned, the lowest temperature found is  $1.3^{\circ}$  at the 250 m. depth. The highest  $S_4^{15}$  is at the 100 m. depth with 1.02564 or S 34.54‰ while the lowest sp. gr. is 1.02056 or S 27.94‰ at the surface in the neighbourhood of C. Etizenzaki. Further, we see that the fresh water-area in Wakasa Bay can be separated into two systems, one of which is the eastern fresh water-mass ( $S_4^{15}$  at the surface below 1.02300 or S below 31.1‰) extending from C. Etizenzaki to Mikuni, and the other the western one which unites the fresh water centered at Ohama Bay and the fresh water ( $S_4^{15}$  below 1.02300) covering Miyadu and Tango Bays. The western fresh water-mass is fed mainly by the small rivers in the western

district such as Yuragawa, and in the eastern district by the rivers, Turugagawa, Kuduryûgawa and others. Between these two fresh water-masses, a comparatively saline water-mass is found intruding upon the area extending from C. Tateisizaki to C. Tunegami.

(b) Distribution of Water Colour and Transparency (see Fig. 4).

The water colour in the area outside of the 200 m. isobathymetric (see Fig. 2) line is a fine blue, II—III in Forel's scale; but in the coastal water area in the interior of the 100 m. isobathymetric line it is remarkably greenish, ranking higher than IV in Forel's scale.

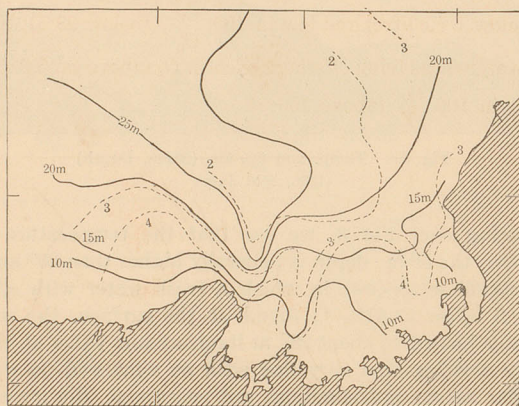


Fig. 4. Water Colour and Transparency  
(1930, Mid July)

— Transparency      - - - - Water Colour  
(Forel's Scale)

On the other hand, the transparency in the oceanic water off the Bay is generally 15—20 m. Its highest value is 29 m., while in the fresh water area previously mentioned it presents notable turbidity, with a value less than 10 m. The water in the area between C. Tateisi and C. Tunegami is comparatively transparent. Hence, on the basis of the distribution of water

colour and transparency we can recognize the fact that a fine, transparent oceanic water is transported into Wakasa Bay by the current directed towards C. Tateisi, and that the turbid fresh water consists of the two systems as mentioned in (i) (a).

(c) Horizontal Distribution of Dissolved Oxygen and its Degree of Saturation (see Figs. 5 a, b).

Generally speaking, the quantities of  $O_2$  and  $100 \frac{O_2}{O_2^s}$  are poor in the coastal water and rich in the oceanic water off the Bay, showing a distribution remarkably resembling that of salinity, water colour and transparency as already described.

Glancing over Fig. 5, we can distinguish again the two coastal water-masses, western and northern, characterized by being poor in  $O_2$  (below 5 c.c./litre) and low in  $100 \frac{O_2}{O_2^s}$ , (below 95%), and the oceanic water-mass lying off-shore, rich in  $O_2$  (above ca. 5.2 c.c./litre) and high in  $100 \frac{O_2}{O_2^s}$  (above 100%).

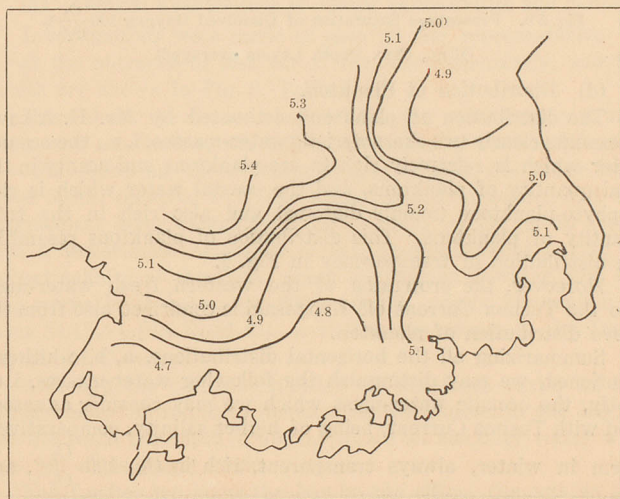


Fig. 5 a. Dissolved Oxygen  $O_2$  cc/lr.  
(10 m., 50 m. Depth Layers averaged)

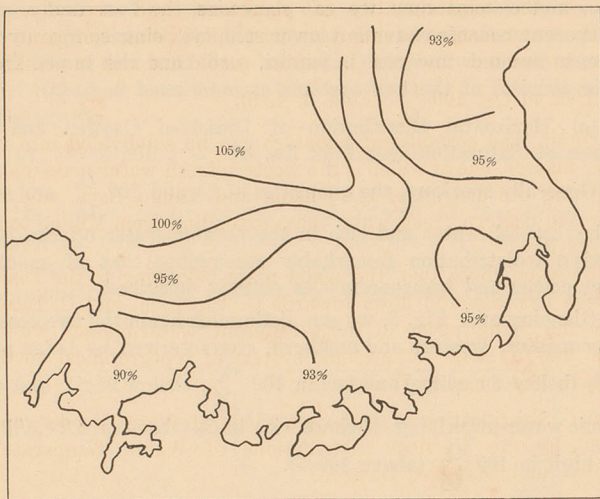


Fig. 5b. Percentage Saturation of Dissolved Oxygen  $100 \frac{O_2}{O_2^*} \%$   
(10 m., 50 m. Depth Layers averaged)

(d) Distribution of Plankton.

The distribution of plankton<sup>1)</sup> estimated by Mr. H. Aikawa represents clearly two characteristic water-masses, i. e., the oceanic water which is relatively rich in zoo-planktons and scanty in the total quantity of planktons, and the coastal water which is rich in phyto-planktons (mainly diatoms) and also rich in the total quantity of planktons. This distribution of planktons resembles the distribution of transparency in Fig. 4.

Moreover, the protrusion of the western fresh water-mass into the Tusima Current off Kyôgasaki is confirmed also from the above distribution of plankton.

Summarizing all the horizontal distributions, a, b, c hitherto mentioned, we may distinguish the following water-masses, i. e., firstly, the oceanic water-mass which we may consider as associated with Tusima Current, being of higher salinity, comparatively warm in winter, always transparent, rich in  $O_2$ ,  $100 \frac{O_2}{O_2^*} \%$ , and

\* In spite of the comparatively poorness of planktons, the quantity of dissolved oxygen is abundant. This fact is perhaps due to the strong water movement in that oceanic water area.

poor in  
coastal  
warm  
and po

Ag  
water-  
occupy  
other t  
Turuga  
Be  
Curren  
From  
infer  
curren

(ii)  
sented  
Salinit

(a)  
In  
in, at  
results

Fr  
therm  
into th  
above  
interm  
with a  
highes  
deep v  
about

Sea na  
Al  
surface  
does no  
a sp. g

Th  
differ  
become

poor in the total quantity of planktons, and secondly, the coastal water-masses having a lower salinity, being comparatively warm in summer and cold in winter, turbid and rich in planktons and poor in  $O_2$ ,  $100 \frac{O_2}{O_2}$  (Figs. 3, 4, 5).

Again, the coastal water-masses can be subdivided into two water-masses, one of which is the western fresh water-mass mainly occupying the district of the Ohama and Tango Bays, and the other the eastern fresh water-mass extending from Mikuni to the Turuga Bay.

Between these two, the water-mass belonging to the Tusima Current intrudes and flows towards C. Tunegami and C. Tateisi. From the configuration of these different water-masses we can infer that a large anticyclonic system of topographical vortical currents is formed in Wakasa Bay.<sup>3)</sup>

(ii) Stratification of Different Kinds of Water-Masses represented by the Vertical Distributions of Water Temperature, Salinity, and Dissolved Oxygen.

(a) Vertical Distribution of Water Temperature and Salinity.

Investigations were made at each of the representative pt. in, at the entrance of and out of the Bay respectively, and the results are shown in Fig. 6, Table I.

From these results we observe that the stratification is another and mesohaline, whence we can classify the stratification into the following three water layers: that is, the upper layer above 50 m., occupied by fresh water named A-water, and the intermediate layer extending from the 50 m. to the 150 m. depth, with a water-mass belonging to the Tusima Current having its highest salinity at the 75 m. depth and named B-water, and the deep water layer below the 200 m. depth, nearly homosaline at about 34.1‰ ( $\sigma_t^{35}$  25.25-25.40), a water-mass proper to the Japan Sea named C-water.

Although the vertical extension of the fresh water of the surface layer is found to increase as we proceed in the bay, it does not reach the depth of 100 m. where we see salty water with a sp. gr. exceeding 1.02550.

The further we leave the bay to the offing, the smaller the difference of salinity between the upper and lower water layers becomes. At the sea district 40-60 miles off C. Tateisi, we find the



Table I. Vertical Distribution of Temperature ( $\theta^{\circ}\text{C}.$ ) and Sp. Gr. ( $\sigma_4^{15}$ ) in July in Wakasa Bay.

District	St.	Depth $\theta_4^{15}$ $\sigma_4^{15}$	Depth											
			0m	10m	25m	50m	100m	150m	200m	250m	300m	400m	500m	
in Bay	35°-44'-20''	$\theta$	24.5	24.0	23.4	21.9	19.4							
	135°-45'-51''	$\sigma_4^{15}$	23.41	24.11	24.46	25.06	25.56	(St. a)						
Entrance	A	35°-59'-7''	$\theta$	23.0	22.5	21.1	19.5	17.6	5.2		1.7			
		135°-47'-30''	$\sigma_4^{15}$	24.81	25.08	25.31	25.57	25.62	25.32		25.30			
	B	35°-55'-23''	$\theta$	26.2	23.6	22.4	20.9	18.6	9.4		3.4		1.4 (274m)	
		135°-33'-20''	$\sigma_4^{15}$	24.20	24.87	24.95	25.32	25.58	25.41		25.26		25.26	
	C	35°-51'-00''	$\theta$	25.2	24.1	23.3	21.7	17.7	4.7					
		135°-40'-00''	$\sigma_4^{15}$	23.97	24.45	24.62	25.00	25.61	25.27					
Exterior of Wakasa Bay	D	$h_3 \sim h_8$	$\theta_{\text{obs}}$	22.6	22.3	21.3	19.5	16.5	9.5		3.1			
		mean		by $\theta = 22.6 - 0.065h$						0 ≤ h ≤ 300 m				
		(Fig. 1)	$\theta_{\text{calc}}$	22.6	22.0	21.0	19.4	16.1	9.6		3.1			
	E	$k_4 \sim k_{11}$	$\theta_{\text{obs}}$	22.0	21.7	20.0	18.2	15.4	7.6		2.2			
		mean		by $\theta = 22.0 - 0.060h$						0 ≤ h ≤ 300 m				
		(Fig. 1)	$\theta_{\text{calc}}$	22.0	21.3	20.4	18.7	15.4	8.8		2.2			
F	$f_{10} \sim f_{15}$	$\theta$	22.3	21.7	18.6	16.2	13.0	9.0	5.0		1.4		0.9 (0.6)	
	mean	$\sigma_4^{15}$	25.17	25.22	25.54	25.63	25.60	25.42	25.29		25.27		25.25(25.33)	

the spring layer of water temperature lies at about the 150 m. depth. The upper part above the spring layer corresponds to the domain of warm water and it is known that some bottom-fishes such as Tai, and Kanagasira which are fond of the water temperature of 17°-18° inhabit its sandy bottom at a depth of 25 m. -50 m.<sup>2)</sup> On the other hand, the lower part below the spring layer corresponds to the domain of cold water and some bottom inhabitants such as crabs and cods which are fond of cold water of 1°-5° are found on its muddy bottom at a depth of 200 m. -250 m.<sup>2)</sup>

It may be said that the position of the spring layer of water temperature in the Japan Sea plays an important rôle on fisheries of mackerel, Ika etc., and of the bottom-fishes mentioned above. For this reason it is desirable in future to make thorough oceanographical observations especially at the depth of the spring layer which lies commonly at 150 m. in the Japan Sea. Generally speaking, since the water temperature is 22°-27° at the surface, 5°-10° at a depth of 200 m., 1°-4° at 300 m., below 1° at 400 m., and 0.5° at 500 m. during the whole year, the difference between the water temperature at the surface and below the 300 m. depth exceeds 20° in summer. This is to be particularly noted as one of the peculiar features of the Japan Sea compared to the Pacific Ocean. The water temperature on the outside of the Bay decreases almost linearly with the increase of the depth, and obeys approximately the relation given by the following formulae:  $\theta = \theta_0 - ah$ , where  $\theta$  denotes the water temperature.,  $h$  the depth in metres. For example, we have

$$\begin{aligned} \text{at St. D} \quad \theta &= 22.6^\circ - 0.065 h \\ \text{at St. E} \quad \theta &= 22.0^\circ - 0.066 h \end{aligned} \quad (0m \leq h \leq 300m) \quad (\text{see Table I}).$$

In other words, the rate of decrease of the water-temperature above the 300 m. depth is 0.65-0.66°C for the present observations.

(b) Vertical Distribution of Dissolved Oxygen and its Percentage Saturation.

The quantity of dissolved oxygen was measured by Winkler's method by Mr. T. Yamasita for the samples obtained from 15 stations in the Bay. Table II indicates the mean values of  $O_2$  and  $100 \frac{O_2}{O_2'}$  at the different layers in the Bay.  $O_2$  contained in

Table II. Dissolved Oxygen and its Percentage Saturation.

Depth	$O_2$ cc/litre	$100 O_2/O_2'$
10 m Layer mean	4.98	97.0 %
50     "     "	5.10	96.9
100    "     "	5.04	91.4
200    "     "	5.52	80.8

the surface layer of Wakasa Bay is about 5 c.c p. ltr. and that in the layer of 50 m.—100 m. depth is about 5.09 c.c p. ltr. The quantity of dissolved oxygen is, however, comparatively abundant in a depth of 200 m. due to its remarkably low temperature. As regards the value of  $100 \frac{O_2}{O_2'}$ , the layer above the 50 m. depth shows about 97%, whereas at a depth of 200 m. it decreases to only 80.8%, with a minimum of 75.8%.

It appears that the number of stations showing supersaturation of oxygen in the upper layer, amounts to 6 and that the most supersaturated one attains a value of 109.4%. The vertical distribution of oxygen also confirms the mode of stratification of the three water-masses above mentioned.

(iii) Seasonal Variation of the Water-masses studied by the Distribution of Water Temperature, Salinity, Colour and Transparency in Each Season.

(a) Water Temperature and Salinity.

Messrs. Kamiya and Kawana<sup>4)</sup> have already discussed the hydrographical features of Wakasa Bay in the normal year and remarked some peculiarities in the seasonal variation of water temperature at a depth of 200 m., i.e., that the maximum lies between Feb. and June, and the minimum between Oct. and Dec. The present author also made some studies on the distribution of the surface water temperature and salinity, as well as of the water colour and transparency for each of the different seasons of the normal year, and tried to investigate the seasonal variation of the results mentioned in (i). (See Fig. 7 a, b, c, d.)

According to Messrs. Kamiya and Kawana,<sup>4)</sup> the water temperature in the upper layer above the 50 m. depth commonly has its maximum in Sept. and its minimum in March; on the other hand, the salinity is high in winter and spring showing its maximum in May while it is low in summer and autumn.

By a glance at Fig. 7, we see that the distribution of water temperature in Feb. represents most clearly an area of the Tusima Current running about 20 miles off the shore, and that a current of warm water with a temperature of 11°–11.5° which is deflected at the entrance of the Bay anticyclonically, progresses to C. Tateisi and C. Tunegami, while along the coastal area there exists a region with water of the temperature of 9°–10°.

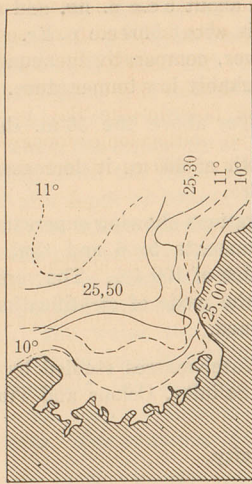


Fig. 7 a. Surface Temp. and Sp. Gr. in Feb. (winter)

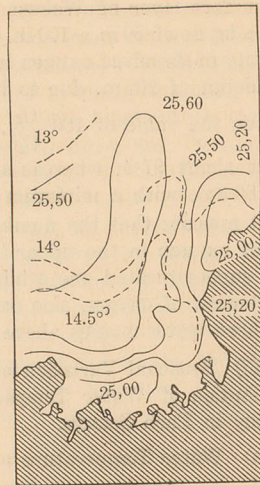


Fig. 7 b. Surface Temp. and Sp. Gr. in May. (spring)

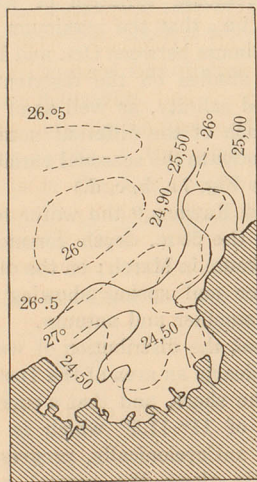


Fig. 7 c. Surface Temp. and Sp. Gr. in Aug. (summer)

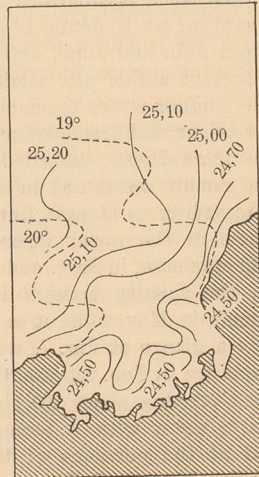


Fig. 7 d. Surface Temp. and Sp. Gr. in Nov. (autumn)

From  
which  
tens  
winte  
over  
durin  
vortic  
and

(

A

autho

the s

which

in su

while

secon

trans

which

as 27

off K

and s

of 10

trans

near

and

it gr

S

porti

the h

high

main

the p

the c

IV

I

stati

curre

From these four figures we may deduce that the Tusima Current, which is flowing in a E-NE direction with a breadth of several tens of miles off the Bay, approaches nearest to the coast in winter and spring and gets away farthest in summer, and moreover that the main features of the flow in the Bay is kept during the whole year, forming an anticyclonic topographic vortical current and two less salty water-masses in the eastern and western parts of the Bay.

(b) Water Colour and Transparency.

According to the result of a previous investigation of the author,<sup>5)</sup> the change in the optical properties of sea water in the seas adjacent to the Bay takes a form of semi-annual change, which may be called the Tusima Current Type; i.e., the maximum in summer and the minimum in spring are especially remarkable, while the secondary maximum in Feb. and March and the secondary minimum in autumn are feeble. In general, the transparent period of the year falls in summer and autumn in which the maximum transparency in August shows values such as 27 m. off Hukui, 26 m. off Kyôgasaki and the water colour off Kyôgasaki is II. The turbid period of the year lies in winter and spring in which the minimum in May shows the transparency of 10 m. off Hukui, and about 13 m. off Kyôgasaki. The most transparent portion approaches nearest to the coast with the nearest approach of the current in April and May (10 miles off) and gets away in summer (in July 50 miles off). In Dec. again it gradually approaches the coast (20 miles off).

Summarizing the above results, we can recognize that the portion of the sea area in which the higher salinity (in winter the higher water temperature as well) occurs combined with the higher values of water colour and transparency represents the main branch area of the Tusima Current, and we can infer from the position of such an area that the Tusima Current is near the coast in winter and spring and far off in summer.

IV. Dynamical Computation of the Currents off the Bay.

Let us assume that the Tusima Current off the Bay is stationary and may be regarded approximately as a density-current,<sup>6)</sup> moreover that frictions are negligible. First, referring



and Sp. Gr.



and Sp. Gr.  
(n)

to the graph of A. Schumacher<sup>6)</sup> and to the table of Hesselberg and Sverdrup,<sup>7)</sup> we can infer the approximate direction of the current from the general trend of the *in situ* isopycnal curves (see Figs. 8 a, b, c) and next, compute the velocities of the current for the given cross sections by Bjerknes's theory, using the formulae  $\Delta v = \frac{\Delta D}{2L\omega \sin \varphi}$  and the true velocity  $V = \frac{v}{\cos \psi}$  (see Fig. 8, Table III).

The result of computation shows that the surface of the Tusima Current flows in a E-NEE direction with a velocity of about 1 knot, which coincides with the results of direct measurement described in the following chapter.

At a depth of 50 m. the computed velocity is 0.5-1 knot, and becomes stronger at 4.50 miles off the coast. Descending to a depth of 100-200 m., the velocity decreases suddenly, and the layers below 200 m. flow slowly with a velocity of 0-0.3 knot.

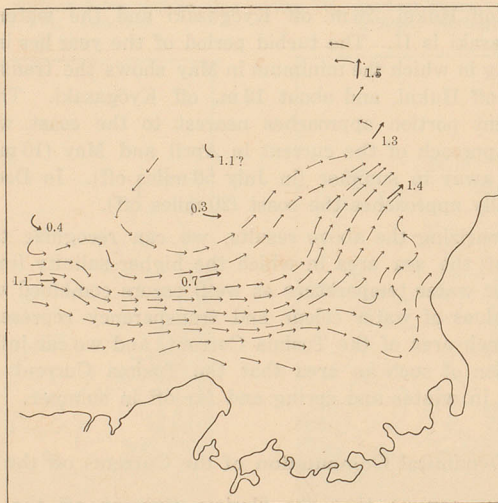


Fig. 8a. Currents computed from Bjerknes's Theory (Surface).  
velocity (sea-miles/hour)

sselberg  
of the  
curves  
current  
ing the  
(see

Tusima  
of about  
urement

not, and  
ing to a  
and the  
knot.

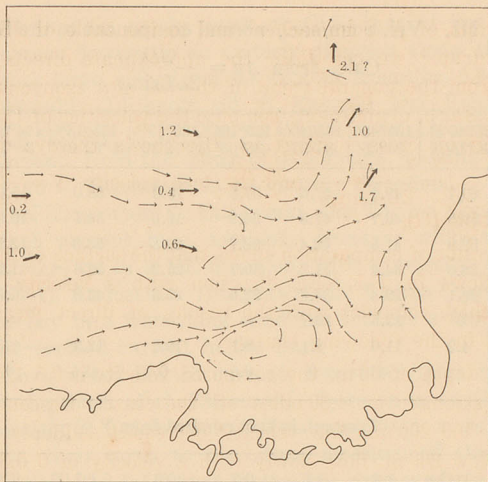


Fig. 8b. Currents computed from Bjerknes's Theory (25 m. Depth).  
velocity (sea-miles/hour)

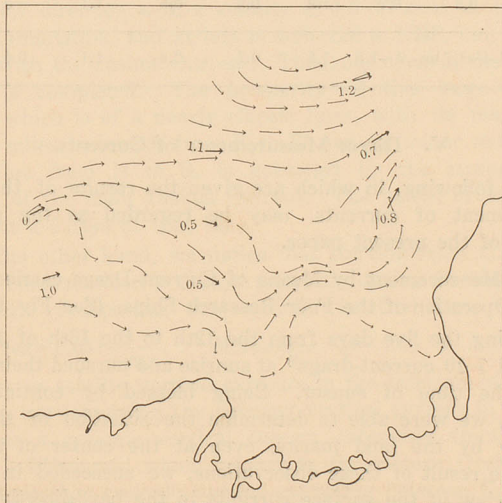


Fig. 8c. Current computed from Bjerknes's Theory (50 m. Depth)  
velocity (sea-miles/hour)

Table III. Vel.  $v$  cm/sec., normal component to the Section

$$\text{Calc. from } \Delta v = \frac{\Delta D}{2\omega L \sin \varphi}$$

Depth	135°46'E 36°15'N	135°43' 36°25'	135°40' 36°37'	135°13' 36°03'	135°13' 36°12'30''	135°13'' 36°22'40''	134°36' 36°12'	134°33' 36°02'
0 m	60.7	49.0	47.0	37.0	15.3	55.0	15.0	56.0
10	59.5	46.7	47.8	34.9	16.6	56.1	16.9	53.2
25	59.0	41.5	52.4	32.7	20.8	58.3	12.1	51.1
50	28.0	34.4	51.2	30.7	25.2	56.6	1.7	50.6
100	26.1	29.4	34.8	22.6	25.8	43.8	-6.7	39.0
150	0	22.5	19.7	—	—	—	—	—
200	4.2	11.6	9.1	8.1	19.2	12.3	-3.0	11.9
300		0	0	0.5	0	0.4	0	0

Depth	True vel. in knot required from $V = \frac{v}{\cos \psi}$							
0 m	1.4 kn	1.3	1.5	0.7	0.3	1.1 (?)	0.4	1.1
10	1.5	1.3	1.5	0.7	0.3	1.1	0.5	1.1
25	1.7	1.0	2.1	0.6	0.4	1.2	0.2	1.0
50	0.8	0.7	1.2	0.8	0.5	1.1	0	1.0

Surface Layer	1.4~1.7 kn	1~1.3	1.5	0.7	0.4	1.1	0.4	1.1
---------------	------------	-------	-----	-----	-----	-----	-----	-----

### V. Direct Measurements of Currents.

The following, in which are given the results of the direct measurement of currents, may be regarded as the principal chapter of the present paper.

(i) Measurement by Means of Current-Drags carried out by the Co-Operation of the Four Research Ships. (See Fig. 9, Pl. I).

During the five days from the 12th to the 16th of July, we liberated 7-10 current-drags<sup>3)</sup> at sunrise and pursued their courses up to the time of sunset. Being blessed by continued fine weather, we were able to determine the situation of the ships precisely by the land marks, even at the center of the Bay. From the result of these observations, we succeeded in getting a clear view of the surface currents in the bay directly, which were already inferred from III. indirectly. Thus, as indicated in

Fig. 9, i  
Tusima  
with a  
off C.  
even wi  
Tusima  
Kyôgas

Aft  
out a b  
current  
1.5 knot  
ing off  
anticycl

The

current

rection

0.5-1.0 k

with a v

drags m

of Ohan

in a N-E

NE of K

parallel

current

current,

about 15

10-15 m

direction

was abo

On

saki the

movemen

$\oint V ds/A$

secondar

ary bays

Bay: i.

Bay to C

area and

zaki an

ction

134°38'  
36°02'

56.0  
53.2  
51.1  
50.6  
39.0  
—  
11.9  
0

1 1.1  
5 1.1  
2 1.0  
0 1.0  
4 1.1

the direct  
principal

ed out by  
. 9, Pl. I).

July, we  
eir courses  
inued fine  
the ships  
the Bay.  
in getting  
ly, which  
ndicated in

Fig. 9, in the region to the west of C. Kyôgasaki we see the Tusima Current flowing in an easterly direction along the coast with a rather large velocity of 0.8 knot off Amarube, 0.5-1.1 knot off C. Nekozaki, 1.5 knots off C. Kanzaki and Kakezu and even with a velocity of 1.5-2 knots which is notably strong for Tusima Current, from the offing of Nakahama, passing near C. Kyôgasaki, to C. Etizenzaki in an easterly direction.

After colliding upon C. Etizenzaki, the Tusima Current lets out a branch current in a southerly direction while the main current marches on in a NE direction, with a velocity of about 1.5 knots off C. Andôzaki. This part of the Tusima Current flowing off the bay in a flourishing condition induces a topographic, anticyclonic vortical current in the Bay.

The above stated branch current, separated from the main current at the south of C. Etizenzaki, flows in a southerly direction towards C. Tateisi and C. Tunegami with a velocity of 0.5-1.0 knot, then turns to a westerly direction off Ohama Bay with a velocity of 0.4-1.0 knot (notice the courses of ten current-drags moving around a centre at 14 miles north of the entrance of Ohama Harbour, and 18 miles east of C. Araizaki), and again in a N-NW direction with a velocity of 0.5-0.7 knot in the area NE of Kamurizima, and at last is deflected to NEE, i.e., running parallel with the Tusima Current. Thus, one cycle of the vortical current is completed. The prosperity of this large vortical current, which is of a nearly elliptic form, with its major axis about 15 miles in length from E to W and its minor axis about 10-15 miles from N to S, is governed by the strength and direction of the main Tusima Current. The period of one cycle was about 4-5 days at that time.

On the other hand, we notice that starting from C. Kyôgasaki the current velocity decays gradually during its anticyclonic movement. Computing the vorticity in the Bay, we have  $\oint Vds/\text{Area} = 3.057 \frac{1}{\text{hour}}$ . Moreover, we find a number of secondary or satellite vortical currents in the interiors of secondary bays, accompanying the primary vortical current in Wakasa Bay: i.e., a cyclonic vortical current extending from Turuga Bay to C. Etizenzaki which belongs to the eastern fresh water-area and another cyclonic current extending between C. Narihuzaki and C. Tunegami which belongs to the western fresh

water-area. There are also other small vortical currents in Tango Bay etc.

These secondary vortical currents are generally feeble and their development may be influenced greatly by the meteorological and tidal conditions. As regards the strong current from Kyôgasaki to Etizenzaki, the independent observations by the three ships, Sôyômaru, Syôwamaru and Tazimamaru, coincide well with each other, pointing to the same result that the stream lines converge remarkably in that region, showing a clear boundary zone (Siwozakai) which is actually proved by a conspicuous discontinuity of water colour and accumulation of drift-algae, water bubbles etc.

(ii) Measurement of Currents by Drift Bottles.

The general outline of the results obtained with drift bottles is shown in Figs. 10a, b, Table IV and it will give an idea of

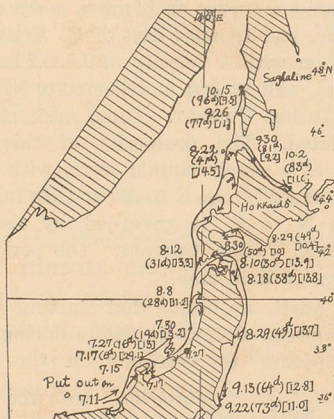


Fig. 10 a. Journeys accomplished by drift-bottles put out on 11th, July.

Figure without brackets shows the month and day of recovery ;  
 ( ) gives number of days "out" and [ ] the corresponding speed in sea-miles per day.

rents in  
 eeble and  
 meteorolo-  
 ent from  
 s by the  
 acide well  
 eam lines  
 dary zone  
 s discon-  
 e, water

ft bottles  
 n idea of

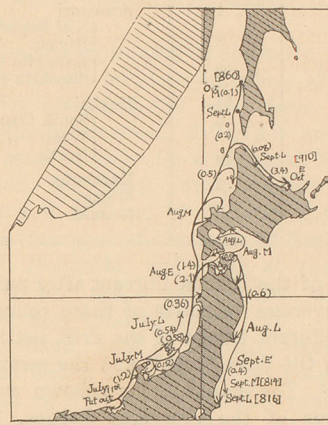


Fig. 10 b. Intermediate velocity (sea-miles/hour) corresponding to each part of month, computed from the recapture of drift-bottles. Distance travelled in sea-miles [ ].  
 E... Early, M... Mid, L... Late.

Table IV. Drift-Bottles thrown overboard in and off the Wakasa Bay.

Put Out	July 11th, 1930. 740 Bottles	Percentage
Recovered	Unto Dec. 1st, 1930. 230 Bottles	31.1%
Details of put out ( $\frac{\text{Recovered}}{\text{Put out}}$ )	Sôyômaru (42/155) Nishûmaru (74/160)	Syôwamaru (73/245) Tazimamaru (36/180)

h, July.  
 ry;

Table IV.—(Continued)

## Details of Recovery

Station Recovered	Bottles	Station Recovered	Bottles
Tottori Pref.	1	Awomori	36
Kyôto	3	• Nisi Tugaru Gun	5
Hukui	28	{ Higasi    "	7
Isikawa	61	{ Kamikita Gun	5
Toyama	11	{ Simokita Gun	19
Niigata	19	Hokkaidô	50
Yamagata	2	{ South Coast	20
Akita	8	{ West    "	26
		{ North   "	7
		Karahuto	4
		Miyagi	2
		Ibaraki	2

the later courses of the Tusima Current after passing out of the Bay and of the average velocities of those courses. In Fig. 10a are drawn the different tracks of the drift bottles, along which are written down the days "out" and the mean velocity during the period "out." The materials here shown were chosen from among the records of the recovered bottles, 230 in number, which are 31.1% of the total 740 bottles "put out," as the most conspicuous examples. In cases when several drift bottles were recovered within a sea-district of a narrow extent which could be considered practically as one spot, the author adopted the first recovered bottle for the computation of the velocity of the current, to give the true velocity as approximately as possible. As some of the bottles took several months to arrive at their destinations, it seems desirable to estimate the velocities in different parts of the tracks. For this purpose the velocity for each period of ten days during the drifting was calculated from  $v = (s_2 - s_1) / (t_2 - t_1) = \Delta s / \Delta t$  and the result is shown in Fig. 10b, together with the tracks of those bottles which traversed remarkably long distances.

From Fig. 10a, we notice that the current flows with a high velocity exceeding 1 knot from Wakasa Bay to Noto Peninsula. From Noto Peninsula to Tugaru Strait it goes on with a velocity of about 0.5 knot. One-third of the total recovered drift-bottles were picked up in the areas adjacent to Noto Peninsula, especially in Nanawo Bay of Toyama Prefecture. Arriving at the western

entrance  
branch  
of 1-2  
coast  
with a  
sea-dis  
travers  
The  
again  
Sôya C  
(its fa  
along  
distan  
throw  
July, s  
coast  
after j  
of abou  
On  
Bay an  
on the  
bottles  
C. Tate  
Ohama  
It  
the bot  
Tottori  
current  
Current  
Ins  
tion of  
Chart,<sup>9)</sup>  
Current  
direction  
to the  
water f  
at the  
normal  
Tho  
Sea tow

Bottles

36  
5  
7  
5  
19  
50  
20  
26  
7  
4  
2  
2

entrance of Tugaru Strait, the current is divided into two branches. One passing through the strait with a high velocity of 1-2 knots in an easterly direction, flows along the Sanriku coast towards the mixed water area of Oyasiwo and Kurosiwo with a velocity of about 0.5 knot and attains its end on the sea-district off Tyôsi, Ibaragi Prefecture. (The total distance traversed, 815 miles).

The other branch, continuing its northerly journey, is divided again at the Sôya Strait into two branches, of which one is the Sôya Current flowing along the coast from Kitami to Tunero (its farthest distance travelled, 910 miles) and the other runs along the west coast of Saghalin arriving at Noda (the farthest distance travelled, 860 miles). Thus, among the drift-bottles thrown overboard in and out of Wakasa Bay on the 11th of July, some were recovered at the coast of Saghalin, some at the coast of Kitami, Hokkaidô, and some at the sea off Ibaragi, after journeys of two and a half months, travelling distances of about eight or nine hundred miles.

On the other hand, most of the drift-bottles put out in the Bay and the area within ten miles off the coast were picked up on the west coast of Noto and in the Bay again. In particular, bottles were abundantly picked up in the neighbourhoods of C. Tateisi, C. Tunegami, C. Araizaki and at the entrance of Ohama Harbour in the Bay.

It may be noted as an extraordinary case that only one of the bottles drifted westerly and was recovered on the coast of Tottori Pref. after 118 days. This is perhaps due to the counter-current developed in autumn, following the decay of the Tusima Current.

Inspecting, for the sake of comparison, the general condition of the Japan Sea in July from our monthly Oceanographic Chart,<sup>9)</sup> we recognize the conspicuous prosperity of the Tusima Current in this month, which was flowing strongly in a northerly direction and had already carried its portion of maximum salinity to the district north of Akita. As the result of it, the seawater from Akita to Saghalin was decidedly more saline than at the corresponding epochs of the former as well as of the normal year, especially in a depth of 100 m.

Though the displacement of the cold water of the Japan Sea towards the south was rather prosperous compared with

the former as well as with the normal year, the sea district along the Japan Islands showed comparatively higher temperatures, so that the isothermal line for 15°C extended to the sea off Niigata-Akita Prefectures and the temperature in the Tusima Channel showed the highest temperature observed during the past eight years. The area from the Tusima Channel to the sea off Simane Prefecture was already covered by a water of sp. gr. less than 1.02500.

(iii) Measurements with Ekman-Merz Current-Meter.

The results obtained with this instrument near Kamurizima are shown in Fig. 11 and Table V. The tidal currents measured are mainly a semidiurnal tide in the surface layer and the low tide occurred at about 1 P.M. of the 16th. The current, not showing much variation down to the depth of 25m., flows at an almost uniform velocity, 0.5–0.7 knot in a westerly direction.

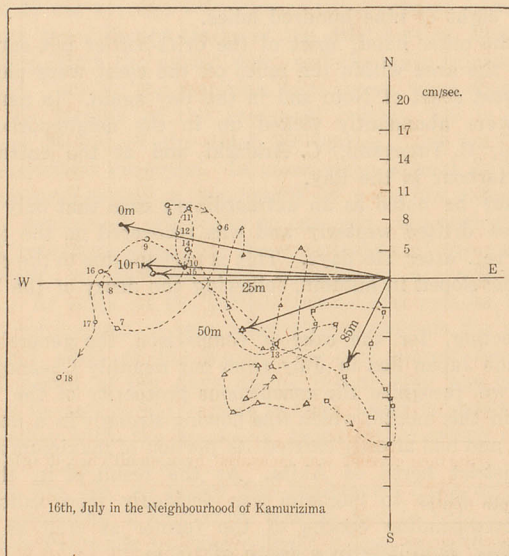


Fig. 11. Vector Diagram of the Currents measured by Ekman-Merz Current-Meter.

T  
Tim  
5.0  
.1  
.2  
6.0  
.1  
.2  
.3  
7.0  
.3  
.1  
.2  
.7  
7.3  
8.0  
.0  
.0  
.0  
.1  
.1  
.2  
9.0  
.0  
.0  
.0  
.1  
.1  
.2  
10.0  
.0  
.1  
.1  
.2  
.3  
11.0  
.0  
.1  
.2  
.4  
Mean  
Strong

Table V. 1930. July 16th 5<sup>00</sup> ~18<sup>30</sup> Sôyômaru, anchored at  
 Kamurizima E, Narihuzaki N (135°23'37''E 35°38'53''N).  
 Ekman-Merz Current-Meter Nr. 152 (H. W. 6<sup>55</sup>,  
 16<sup>40</sup> L. W. 11<sup>20</sup>).

Time	Depth	Velocity	Direction	Time	Depth	Velocity	Direction
	m	cm/sec.			m	cm/sec.	
5.08	25	25	N 70° W	12.00	0	26	W
.19	50	17	N 80° W	.03	10	26	S 85° W
.28	85	16	S 8° W	.12	25	23	N 77° W
				.20	50	17	S 33° W
				.30	85	5	S 10° W
6.03	10	23	N 80° W				
.11	25	19	N 2° W	13.00	0	26.5	W
.20	50	17	N 22° W	.00	10	16	N 82° W
.30	85	13	S 25° W	.08	25	14.5	S 58° W
				.17	50	20	S 48° W
7.01	10	20	N 80° W	.28	85	8	S 15° W
.36	25	30	S 79° W				
.18	50	18	N 80° W	14.00	0	35.5	W
.27	85	15	S 60° W	.00	10	20	W
7.30	0*	27	N 75° W	.07	25	22	N 80° W
				.17	50	22	S 50° W
				.26	85	13	S 3° W
8.00	0	24.7	N 68° W				
.00	10	26.0	W	15.00	0	36.8	S 85° W
.08	25	31	W	.00	10	27	W
.18	50	18	S 80° W	.07	25	23	N 86° W
.28	85	8.5	S 50° W	.16	50	21	S 60° W
				.25	85	14.5	S 2° E
9.00	0	28.4	N 75° W				
.00	10	27	N 71° W	16.00	0	34.0	W
.09	25	26	N 80° W	.00	10	34.0	N 86° W
.18	50	16	S 60° W	.08	25	29	S 80° W
.28	85	17	S 54° W	.19	50	17	S 56° W
				.29	85	14	S
10.00	0	25.9	N 75° W				
.02	10	24.5	N 83° W	17.00	0	30	N 85° W
.10	25	22	N 85° W	.00	10	36	S 83° W
.28	50	13	S 79° W	.08	25	32	S 80° W
.38	85	10.5	S 60° W	.16	50	22	S 50° W
				.26	85	18	S
11.00	0	24.0	N 38° W				
.02	10	31.5	N 70° W	18.00	0	32	N 85° W
.12	25	23	N 70° W	.00	10	31	S 74° W
.21	50	12	S 70° W	.07	25	36.5	S 74° W
.43	85	11	S 65° W	.16	50	17	S 50° W
				.25	85	16	S 28° W

(\*Surface current was measured by a small curr-drag)

Depth (metre)		0	10	25	50	85
Mean	velocity cm/sec.	29.2	26.3	25.8	17.6	12.8
	current direction	N 78° W	N 86° W	N 87° W	S 71° W	S 27° W
Strongest	velocity cm/sec.	36.8	31.0	36.5	22.0	18.0
	direction	S 85° W	S 87° W	S 74° W	S 50° W	S

Below 25 m., the current is deflected gradually to a southerly direction, i.e., in the cyclonic sense, and at last to a SSW direction, descending to a depth of 85 m. It is regrettable that the present measurement could be carried out only once during 14 hours near Kamurizima.

#### VI. Concluding Remarks.

Summarizing the general features of the surface currents in the inside and outside of Wakasa Bay as deduced from the results of the indirect computation and the direct measurement described above in Chapters III, IV and V, a synthetic current chart is constructed and shown in Fig. 12, Pl. I. According to III (iii), the features of the current systems here shown seem to be kept nearly constant during the whole year.

Here it is to be remarked that the large vortical current in Wakasa Bay is not entirely closed, nor is it a two dimensional vortical current, but that the remarkable convergence of the stream lines along a zone extending from Kyôgasaki to Etizenzaki as already mentioned and the existence of a conspicuous water boundary suggest that some descending motion is to be assumed along a sloping surface of discontinuity, formed by the creeping of the oceanic water under the coastal water. As there may exist no sink and source in the Bay, it must be understood that from the eastern part of the entrance of the Bay a moderate quantity of the oceanic water is continually flowing into the Bay, and, on the other hand, the coastal water continually mixing with the oceanic water on the boundary zone is somewhere being continually taken out from the Bay.

According to A. Defant,<sup>10)</sup> when the upper and lighter water layer is rotating anticyclonically with a velocity higher than the velocity of the lower water, the upper surface of the upper water-mass is convex upward at the centre of rotation while the surface of the lower heavy water-mass is convex downward. In our present case, examining the trends of the isopycnals *in situ* in the cross section of the primary vortical current in Wakasa Bay along its major and minor axis respectively, we recognize that in the region below the 200 m. depth some tendency is shown similar to that above after A. Defant, though not quite so remarkably.

Fig. 12. Currents in Mid July, 1930  
inferred from our Investigation;  
Velocity (sea-miles/hour)

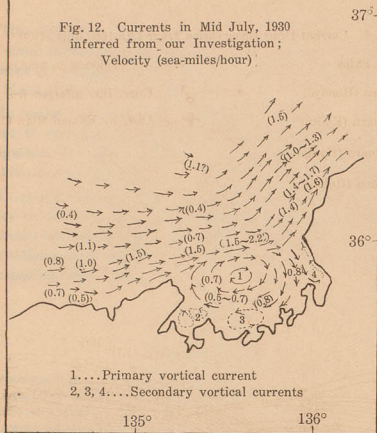
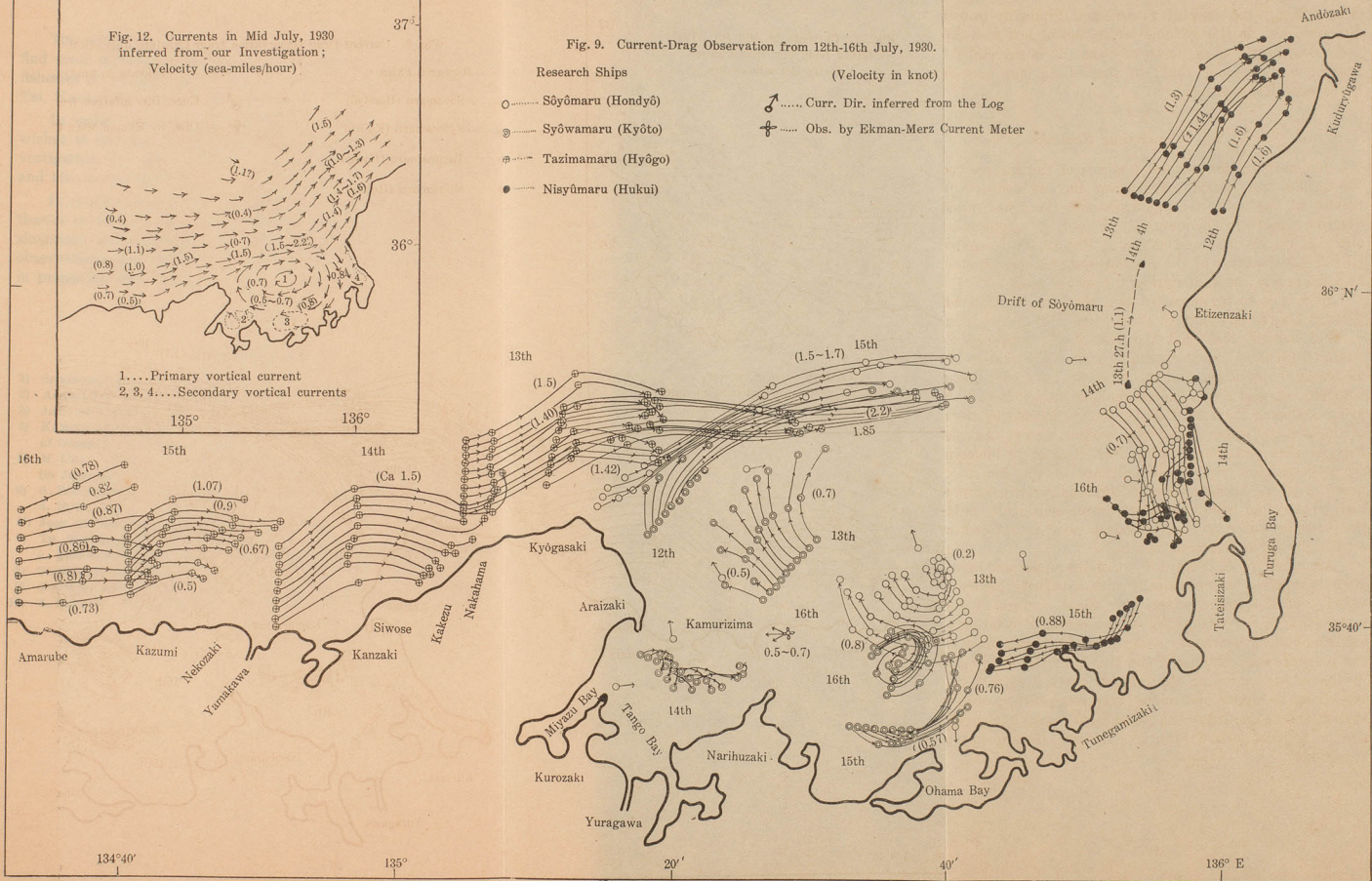


Fig. 9. Current-Drift Observation from 12th-16th July, 1930.  
(Velocity in knot)

- Research Ships
- ..... Sôyômaru (Hondyô)
  - ⊙..... Syôwamaru (Kyôto)
  - ⊖..... Tazimamaru (Hyôgo)
  - ..... Nisyûmaru (Hukui)
- (Velocity in knot)
- ♂..... Curr. Dir. inferred from the Log
  - ♀..... Obs. by Ekman-Merz Current Meter



The results of the present hydrographical investigations may find some application in the problems regarding the conditions of fisheries of mackerel, Ika, Buri and bottom inhabitants such as Tai, Kanagasira, Karei, crab and cod.

In order to complete research in the same line the author wishes to be able to undertake in the near future a similar investigation for each season respectively, especially for winter, and also an investigation of the bottom current in the bay.

In concluding this paper, the author wishes to state his sincere thanks to all the crew of the ships Sôyômaru, Syôwamaru, Tazimamaru and Nisyûmaru for their zealous aid given during the observations, and also to Prof. T. Terada for his kind advice given in preparing this report.

---

#### Literature Cited

- 1) Semiannual Rep. of Oceanogr. Invest., No. 47, Tôkyô, Japan.
- 2) Annual Rep. of the Hukui Fish. Expt. St., 1920-27.
- 3) Jour. of Oceanogr., Vol. 2, No. 1, 2, pp. 29, 43, 163.
- 4) KAMIYA and KAWANA: Oceanographical features of Wakasa Bay. Annot. of Oceanogr. Researches, Vol. 2, No. 1 (1928), p. 15.
- 5) M. UDA: Water Colour and Transparency in the Seas Adjacent to Japan (in Japanese). Umi to Sora, Vol. 10, No. 8, Part I (1930).
- 6) A. SCHUMACHER: Graphische Ermittlung von  $\sigma_t$  auf  $t^\circ\text{C}$  auf. S%. Ann. d. Hydr. u. mar. Meteor., (1922), p. 305.
- 6') Jour. of Oceanogr., Vol. 2, No. 2, p. 179 (Kôbe).
- 7) TH. HESSELBERG u. H. U. SVERDRUP: Beitrag zur Berechnung d. Druck u. Massenverteilung in Meer. Bergens Museums Aarbok, 1914-15, Nr. 14.
- 8) Semiannual Rep. of Oceanogr., No. 46, p. 247 Miscellaneous.
- 9) Monthly Oceanogr. Chart., No. 131, the Imp. Fish. Expt. St., Tôkyô, Japan.
- 10) A. DEFANT: Dynamische Ozeanographie (1929), p. 110.



Printed by  
KOKUSAI SHUPPAN INSATSUSHA  
International Publishing & Printing Co  
No. 6 Nichome, Yurakucho  
Kojimachiku, Tokyo