Hydrographical Studies Based on Simultaneous Oceanographical Surveys Made in the Japan Sea and in its Adjacent Waters during May and June, 1932.

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(With 13 Tables and 36 Figures in the Text)

ABSTRACT.

This report deals with the simultaneous hydrographical conditions in the Japan Sea and its adjacent waters for a certain period about June 5, 1932.

The investigations were carried out with the collaboration of about fifty boats belonging to the fisheries authorities in Japan. On the basis of the records and samples thus obtained, the bottom configuration and the deep sea-deposits are newly described.

The actual conditions as to distributions of water temperature, salinity, water colour and transparency, O_2, 100 O_2/O_2', pH, P_2O_5, SiO_2, N_2O_5-N_2, and meteorological conditions of that period are shown. The currents were measured by means of a number of drift-bottles cast overboard, and also by current-drags and current-meters. Dynamical computations of currents are also given.

Summarizing these investigations, a synthetic current chart was constructed. Besides, the stratification of several distinct water-masses, and the characteristic features of each region of the explored water-area were investigated.

The general trends of currents and the nature of the water characteristic of of the Japan Sea are also discussed, as also the correlations between the hydrographical, the biological, and the fisheries conditions.

In general, abundance of plankton coincides with abundance of nutrient salts and also with the existence of regions of upwelling water.

Some anomalies of fisheries conditions in this season, especially the unfavourable conditions of the mackerel and sardine fisheries, were fonnd to correspond with anomalies in the hydrographical conditions thus obtained.

I. Introduction.

In order to follow more closely the line of investigation taken in the past by the vessels "Vitiaz" (1894),[1] "Ten'Ô Maru" (1919–21),[2] "Yamato" (1923, 24),[3] "Syunpû Maru" (1928–32),[4] etc., an extensive oceanographical investigation of the Japan Sea was recently carried out, practically simultaneously, during May and June, 1932, by our research boat "Sôyô Maru" (202 tons) assisted by about 50 boats, all of nearly the same build and belonging to the local authorities. An important feature of these observations is that they were begun simultaneously (June 5) in all the localities to be studied. The area explored extends from the sea off Karahuto (50° N) in the north to the South China Sea (20° N) in the south practically all the seas west of the Japanese Islands.

This paper deals with the results of the hydrographic observations and with the relations found to exist between fisheries and hydrographical and biological conditions. For fuller details the reader is referred to the Semi-annual Reports of Oceanographical Investigation, Nos. 50 and 51, published by the Imperial Fisheries Experimental Station. The data obtained by the "Sôyô Maru" has largely been drawn upon in this paper.

II. General Aspect of The Observations.

The observing stations are indicated in Figs. 1a and 1b. The number of stations involved, water samples obtained for the chlorine titration, and current-bottles thrown overboard totalled about 1700, 6500, and 6800, respectively. During the period from May 5 to June 26, our research boat "Sôyô Maru" cruised nearly 4000 sea-miles and carried out observations at 182 stations.

III. Equipment, Methods employed, etc.

In the case of the "Sôyô Maru" and the "Misago Maru", water temperature was observed with reversing thermometers patterned after Negretti and Zambra and also after Richter and Wiese, attached to Nansen's water bottle, with the necessary corrections applied. The other boats used Kitahara's insulating

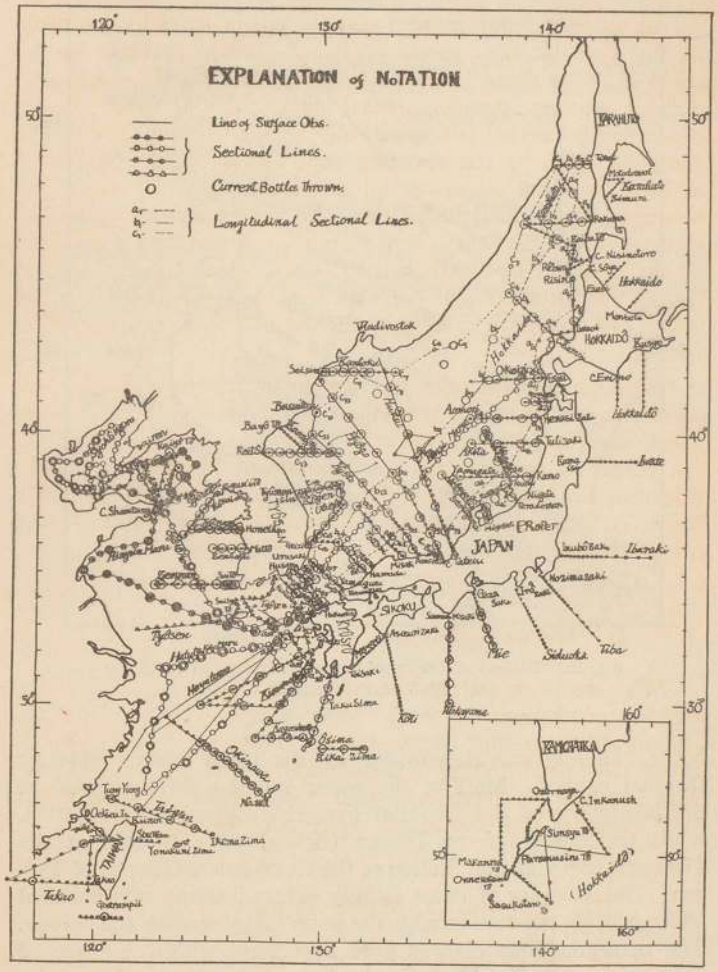


Fig. 1a. Oceanographic Sectional Lines and Stations. (Simultaneous Observation in May and June, 1932).

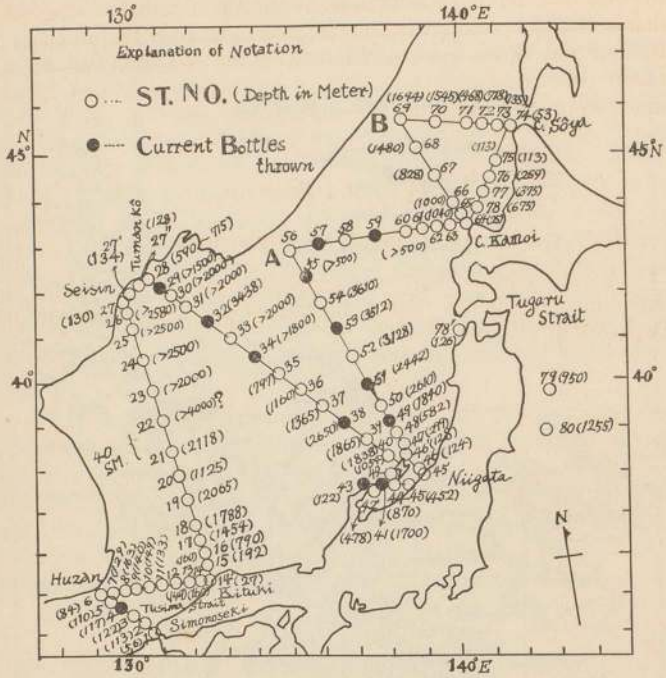


Fig. 1b. Stations of Observation and Soundings in Meter by "Sôyô Maru" in 1932.

bottle. Salinity was determined by the usual Mohr's chlorine titration method. Most of the water samples were titrated at the laboratory of the Imperial Fisheries Experimental Station, while the samples from Tyôsen (Korea) were titrated at the Fisheries Experimental Station of the Government-General of Tyôsen. The accuracy of these salinity determinations was checked by comparing the results with the same samples after the survey. The determinations showed good agreement within a range of accuracy of 0.02 ‰. The dissolved oxygen was determined by Winkler's method, pH by the ordinary colorimetric method, phosphate and silicate by Atkins' improved method, N_2O_5-N_2 by the methods of Diénért, Wandenbulcke, and Atkins. In order to check

the observed depth (Dg), obtained by the meter-gauge, we computed depth (Dc) by using the unprotected reversing thermometer of Richter and Wiese in conjunction with the protected one. It was found that the two values of the depth thus obtained differed more from each other as the sea-waves became higher.

IV. Sea Bottom.

(1) Bottom Configuration.

A bathymetric chart was drawn by inserting in it the new sounding data in the chart published by the Naval Hydrographic Department (Fig. 2).

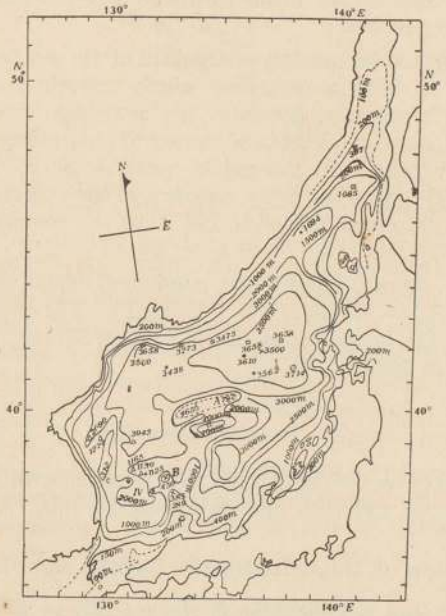


Fig. 2. Bathymetric Chart of the Japan Sea.
a...Yamato-Tai. b...Syunpû-Tai. c...Uturyô-Tai. d...Musasi-Tai.
A, B....new banks discovered.
⊙ Japanese Navy. ● Sôyô Maru. △ Misago Maru. ⊡ USSR.

A new shallow region (A) (sounding depth 797 m., deposit white SM) which was discovered north of the "Yamato-Bank", is supposed to be a continuation of the bank discovered by the "Syunpû Maru" in 1930.[4] Another new bank (B) and a ridge may be noticed lying east of Takesima, north of Oki-no-Sima.

After the "Sôyô Maru" had sounded a depth of 1125 m. at St. 20 (37°55′10″ N, 131°27′25″ E). the "Misago Maru" obtained one of 1130 m. at 37°53′ N, 131°20′ E and 1162 m. at 37°49′30″ N, 130°56′ E, in the neighbourhood of St. 20.[5] Lastly, a shallow bank (B), sounded by the "Tazima Maru" with a depth of 450 m., is worthy of special attention. Since a deep, exceeding 2000 m., lies between this area and Uturyô-Island, the existence may be inferred of a ridge extending from the eastern side as a branch of the "Oki no Sima—Yamato Tai" Ridge. The sounding data from the dredge survey made by the "Sôyô Maru" in 1928-30 are also inserted here.[5]

Considerable knowledge was gained of the sea bottom of the eastern sea off Siberia, regarding which scarcely anything was known. Unfortunately, however, the soundings from St. 55 to St. 64 could not be carried out according to programme on account of stormy weather. In the region north of St. 65, a deep was found near the Siberian coast, contrary to our expectations. For example, at St. 69 (45°36′50″ N, 138°25′20″ E), soundings showed 1694 m.

In our present survey the maximum depth sounded was 3610 m. at St. 54 (41°40′55″ N, 135°56′ E), The greatest depth recorded so far in the Japan Sea is that of 3714 m., by H. M. S. "Yamato" in 1924.

(2) Bottom Deposits.

Samples of the bottom deposits were obtained with Marukawa's bottom snapper and with Sigsbee's sounding tube.

Classification of Deposits for the Depths sampled (Tab. 1).

In the Japan Sea, in general, the sea bottom at depths less than 150 m. show deposits mixed with terrigeneous sand, while at depths greater than 200 m. it is muddy. Classifying further the muddy deposits from the point of view of colour, the mud

Table 1. Relation between Botom Deposits and Depth of the Bottom. ("Sôyô Maru," 1932.)

Bottom	Freq. No. of Bottom Deposits				Colour of M. & MS.				Bottom
Depth (meter)	S (r. g)	SM	MS	M	White, Yellow	blue	Upper red lower blue	red (brown)	Classification
0– 50	1	—	—	—	—	—	—	—	I. Terrigeneous Sandy Zone
50– 100	1	1	—	1	—	1	—	—	
100– 150	9	—	6	5	1	10	—	—	
150– 200	—	—	1	3	—	4	—	—	II. Blue Mud Zone
200– 400	1	—	1	2	—	3	—	—	
400– 600	—	—	1	1	—	2	—	—	
600– 800	—	1	—	3	—	3	—	—	
800–1000	—	—	—	2	—	1	1	—	
1000–1200	—	—	—	4	1	1	2	—	
1200–1400	—	—	—	1	1	—	—	—	III. Upper Red, Lower Blue Mud Zone
1400–1600	—	—	—	4	—	2	1	1	
1600–1800	—	—	—	3	—	1	2	—	
1800–2000	—	—	—	3	—	—	3	—	
2000–2200	—	—	—	2	—	—	2	—	IV. Red (?) Mud Zone
2200–2600	—	—	—	1	—	—	1	—	
2600–3000	—	—	—	2	—	—	1	1	
> 3000	—	—	—	3	—	—	—	3	

from 200 m. to 1500 m. depth is of dark greenish-blue tint (probably the so-called blue mud). From 1600 m. to 3000 m., the upper part is of red and the lower of blue mud, but beyond that we find red-brown mud, although the quantity is scanty. It would be well to state here that in the northern regions (from St. 65 to St. 70) of the Japan Sea, the reddish brown colour in the upper stratum of mud at the bottom prevails at comparatively shallower depths than in the southern regions of the same sea.

In short, the deposits in the Japan Sea may be classified into four zones as shown in Tab. 1. The red or reddish brown colour in the upper stratum of mud may be due to oxidation of the blue mud.

Remarks on Certain Bottom Deposits.

A peculiar sample was obtained from the bottom at a depth of 2065 m. at St. 19 (37°18′05″ N, 131°46′ E), clearly showing stratification. The total length of the mud brought up in the

sounding tube was 11 cm., of which the uppermost reddish mud measured 2 cm., and the next layer, of dark greenish blue mud, 9 cm. Under the latter layer we found coarse, white crystalline sand particles adhering to the base of the mud. It was the object of much curiousity. The deposits in the vicinity of the "Yamato-Bank" also show some strange features when compared with the general character of the Japan Sea deposits. For example, the sample from St. 35 (new shallow region A above mentioned) is white SM, while that from the bottom of St. 36, lying east of "Yamato-Bank" (39°48′20″ N, 135°15′ E, depth 1160 m.) is a reddish-brown sandy mud. Further, at St. 37 (39°25′ N, 135°57′ E, depth of bottom 1365 m.) we found an ash-coloured clay-like mud, while from the bottom of St. 53 (41°04′55″ N, 136°22′40″ E, depth 3562 m.) we obtained several brownish-black mud concretions adhering to the interior of the sounding tube.

The above descriptions of the deposits are based on naked-eye observations made at the time of sampling. The results of the chemical and mineralogical studies will be published later.

Table 2. Bottom Deposits in the Japan Sea along the Coast of Japan Proper. ("Sôyô Maru," 1929.)

Bottom	Freq. No. of Bottom Deposits						Total	% of Freq.						
								(A)					(B)	
Depth (meter)	r	g	s. p	SM	MS	M	Freq. No.	r	g. p. S	SM	MS	M	r. g. p. S. SM.	MS. M.
25– 50	1	—	1	—	—	—	2	**50**	**50**	0	0	0	100	0
50– 75	2	—	3	3	—	1	9	22	**34**	33	10	11	89	11
75–100	2	1	8	2	2	3	18	11	**50**	11	11	17	72	28
100–125	3	3	14	1	7	4	32	10	**51**	4	22	13	65	35
125–150	6	1	13	3	3	2	28	22	**50**	11	10	7	83	17
150–175	4	—	4	—	2	1	11	**36**	**36**	0	19	9	72	28
175–200	—	1	2	3	3	4	13	0	23	23	23	**31**	46	54
200–225	1	1	2	5	2	2	13	8	23	**40**	15	14	71	29
225–250	1	2	1	—	2	4	10	10	30	0	20	**40**	40	60
250–275	2	—	1	—	4	2	9	22	11	0	**45**	22	33	67
275–300	—	—	—	—	1	2	3	0	0	0	33	**67**	0	100
300–325	1	—	—	—	—	2	3	33	0	0	0	**67**	33	67
325–350	1	—	—	—	1	4	6	17	0	0	17	**66**	17	83
350–400	1	—	—	1	—	—	2	Gothic figures denote max. % of freq.						
400–450	—	—	—	—	2	6	8							
450–500	—	1	—	3	—	2	6							
> 500	—	2	1	0	—	5	8							

Sea Bottom along the Coast of Japan Proper. (Tab. 2).

A glance at Tab. 2, which is based on the survey carried out by the "Sôyô Maru" in the summer of 1928–30,[5] will show that the percentage of mud is less than 35 % at bottoms less than a depth of 150 m., increasing conspicuously in the bottom zone at depths of 150–300 m., and exceeding 60 % at bottoms of a greater depth than 250 m.

IV. Meteorological Conditions (Air Temperature, Difference between Air Temperature and Water Temperature, Sea Fogs, and Winds).

As to the meteorological conditions about June 5, we first plotted the distribution of air temperature over the Japan Sea (Fig. 3). It will be seen that the air temperature is higher in the southern part of the Sea and along Japan Proper, but lower along the continental side in the northern and western part of the Japan Sea. A glance at the isallo-curve chart of the difference between air temperature and water temperature on the surface of the sea (Fig. 4) will show that the air temperature at the time was in general higher than the water temperature. The temperature excess is high in the eastern part of the Japan Sea, and relatively low in the western part of the sea.

Inserting the distribution of winds and sea-fogs at that time in Fig, 4., we find a close correlation between them. Although sea-fogs did not appear in regions where the air was warmer than 3°C above that of sea water, they appeared most frequently where the air temperature was only slightly (0°–1°C) higher than the water temperature.

It is remarkable moreover that areas with temperatures exceeding 3°C correspond to areas of prevailing southerly winds, whereas those in which fogs appeared most frequently correspond to areas of prevailing easterly and north-easterly winds.

V. Diurnal Variation of the Hydrographical Elements and the Accuracy of the Isolines drawn in the Sea investigated.

The diurnal amplitudes of water temperature, salinity, and transparency observed hourly in the course of current measure-

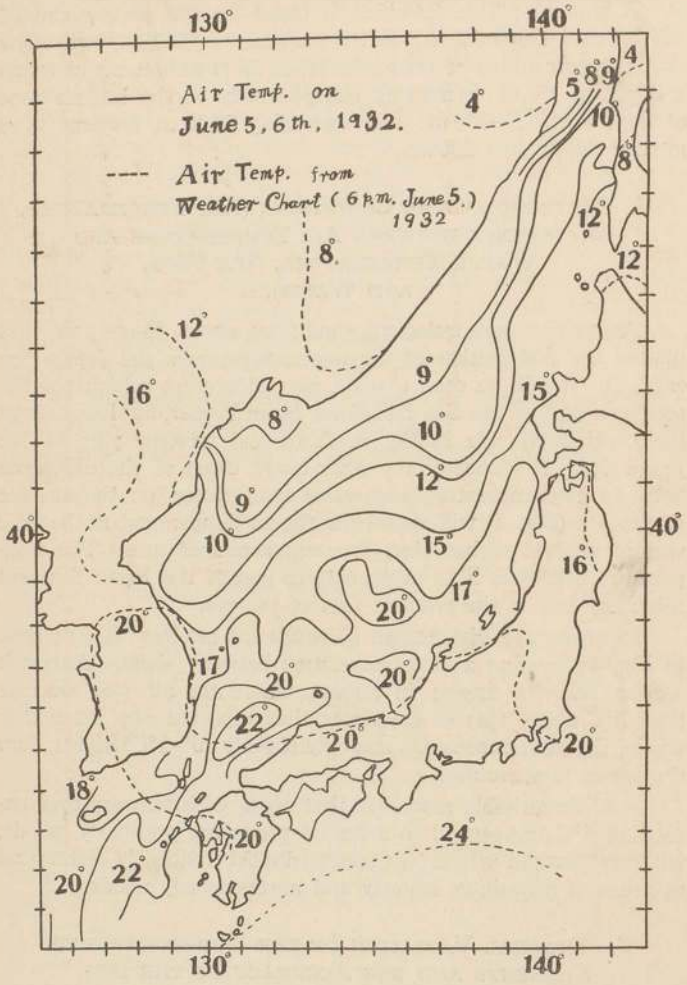


Fig. 3. Distribution of Air Temperature over the Japan Sea.

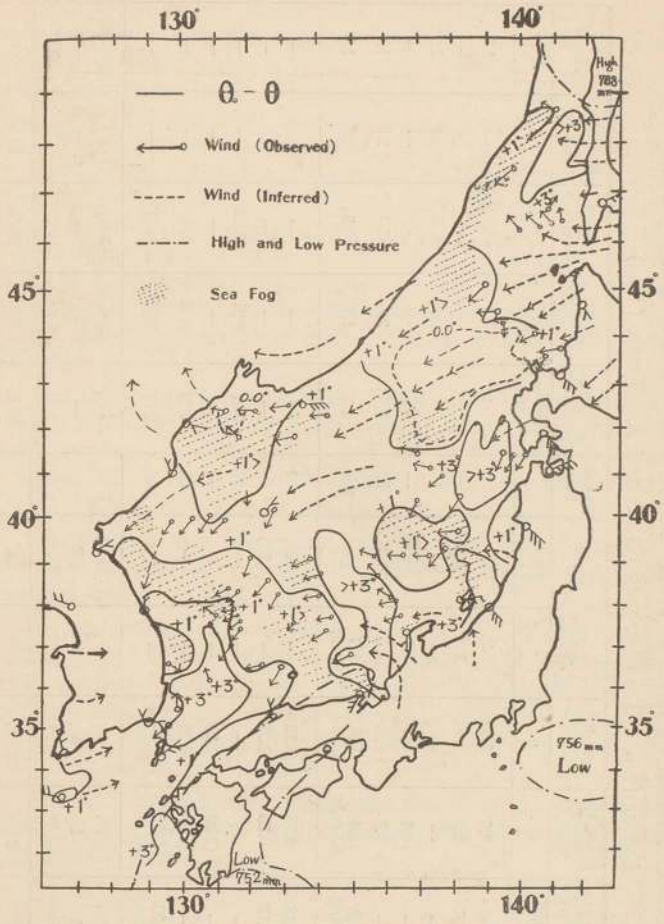


Fig. 4. Sea Fog, Wind and the Difference between the Temperature of Air (θ_a) and of Water (θ) at the Sea Surface.
(June 5-6, 1932.)

ments with the Ekman-Merz current meter in the Japan sea, Yellow Sea, Pwok Hai, the East China Sea (Tung Hai), and the Strait of Formosa, are shown in Tab. 3.

Table 3. Diurnal Variation of Water Temp., ($\theta_{amp.}$) Salinity, ($S_{amp.}$) Water Colour ($F_{amp.}$), Transparency ($D_{amp.}$) and Air Temp. ($\theta'_{amp.}$).

St. (Long. (E) / Lat. (N))		Pwok Hai 37°-52′-39″ 119°-35′-15″	Yellow Sea 36°-02′ 122°-32′	Tung Hai 31°-44′-30″ 124°-50′-30″	Strait of Formosa 24°-30′-10″ 120°-15′-00″	Mean	Japan Sea	No'o 37°-39′-16″ 137°-21′-06″	Sado 38°-22′-24″ 138°-29′-17″	Aomori 41°-03′-10″ 140°-08′-14″	Hokkaido 43°-22′ 140°-21′	Mean
Date		1932 VI. 5	" "	" "	" "	1932 VI. 5		1932 V.	" VI. 13	" VI. 17	" VI. 10	1932 VI
	m. 0	4.0	0.5	2.5	0.7	1.9	m. 0	1.4	0.3	1.6	—	1.1
	5	2.5	0.3	1.9	1 0	1.4	—	—	—	—	—	—
$\theta_{amp.}$	—	—	—	—	—	—	10	0.9	0.6	0.9	3.6	1.5
(C°)	20	—	0.4	0.6	0·8	(0.6)	—	—	—	—	—	—
	40	—	0.7	0.6	1.0	(0.8)	50	0.4	2.6	2.4	1 5	1.7
	bm.	1.9 (12 m.)	0.4 (67 m.)	0.5 (50 m.)	1.3 (60 m.)	1.0	100	1.1	1.7	0.5	1.6	1.2
	m. 0	0.18	0.27	0.38	—	(0.28)	m. 0	—	—	—	—	—
	5	0.18	0.25	0.38	—	(0.27)	—	—	—	—	—	—
$S_{amp.}$	—	—	—	—	—	—	10	0.07	0.31	0.31	—	—
(‰)	20	—	(0.99)	0.20	—	—	—	—	—	—	—	—
	40	—	(0.93)	0.20	—	—	50	0.14	0.32	0.16	—	—
	bm.	0.23 (12 m.)	0.25 (67 m.)	0.52 (50 m.)	—	(0.32)	100	0.07	0.13	0.31	—	—
$D_{amp.}$		3 m.	3 m.	3 m.	—	(3 m.)		7 m.	2 m.	8 m.	—	(5.7 m.)
$F_{amp.}$		1	1	4	1	1.8		—	—	—	—	—
$\theta'_{amp.}$		5.0°	4.8°	6.6°	3.2°	4.9°		2.7°	0.8°	4.4°	4.8°	3.2°
Time Interval		28 h.	28 h.	26 h.	10 h.			13 h.	13 h.	26 h.	24 h.	

On account of the shallowness of the Yellow Sea and the Pwok Hai, the strong tidal current in these seas causes the heat energy from solar radiation to be carried from the upper layer of the water to the lower. Hence, in spite of its perfect stratification, no vertical oscillation of water layer (internal wave) occurs in the Yellow Sea and the Pwok Hai. In the Japan Sea, however, the internal wave with its phase nearly coinciding with the tidal waves, is conspicuous in the districts along the coast of Japan Proper facing the Japan Sea. From Table 3 it will be seen that a diurnal amplitude of 1°C in the water temperature and of 0.1–0.3 ‰ in the salinity are common in this season. It should be noted however that as the above results were obtained in the coastal water-area, these variations may be greater than in the open sea.

The thermograms obtained by a self-recording thermometer of Negretti-Zambra pattern have shown diurnal amplitudes of water temperature of 0.5°, 0.7°, 1.4°, 0.8°, 1.0°C in the harbours of Kituki, Seisin, Sado Hutami, Niigata, and Odaru, respectively, an average of about 1.0° for all the harbours.

Areas also with a steep horizontal water temperature gradient, as on the boundaries of cold and warm water-masses, sometimes show a gradient of 1.0°C per 3 to 15 sea-miles.

On the other hand, from observations of the " Misago Maru " and the " Sôyô Maru " made at approximately the same stations off Suigentan and Seisen on the east coast of Tyôsen and repeated after several days, the amplitude of water temperature variation in the upper layer above depths of 100 m., may easily amount to 1° after the lapse of a week.

Summarizing the above mentioned results, it may be admissible to plot the isotherms for this season with an interval equal to or greater than 1°C.

VI. Horizontal Distribution of Water Temperature and Salinity.

In order to plot on a chart the distribution of water-temperature and salinity in the upper layer, above depths of 100 m., we adopted the data for early June, whereas for the lower layer beneath depths of 150 m. we adopted the data for the interval



Time Interval | 28 h. | 28 h. | 26 h. | 10 h. | | 13 h. | 13 h. | 26 h. | 24 h.

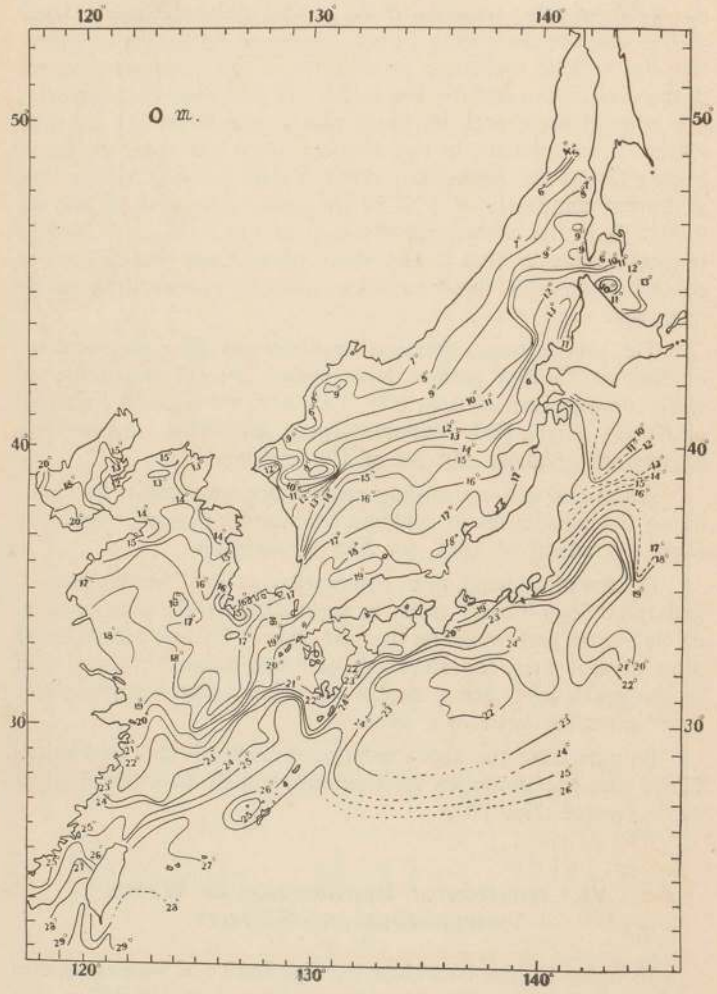


Fig. 5. Surface Water Temperature.
(Early June, 1932.)

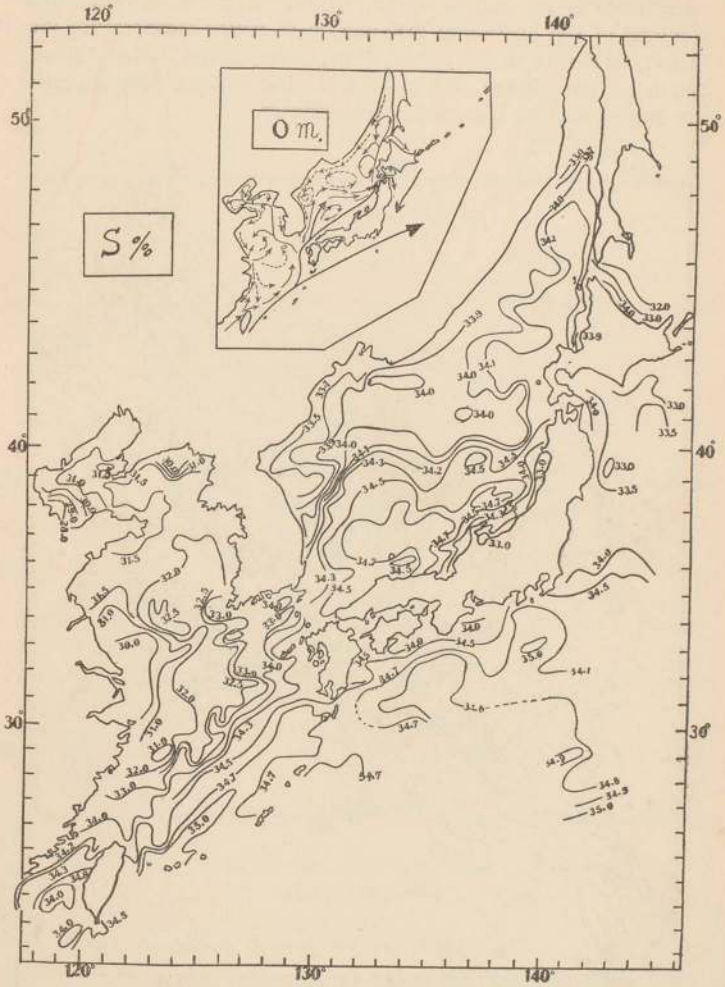


Fig. 6. Salinity and Inferred Current-Systems at the Surface. (Early June, 1932.)

between May 15 and June 20 (that is for about a month with early June as the middle of it). In this way charts were constructed of the horizontal distribution of water temperature and salinity at depths of 0 m., 10 m., 25 m., 50 m., 100 m., 150 m., 200 m., 300 m., 400 m., 500 m., 600 m., 800 m., and 1000 m. These charts are reproduced in Figs. 5–17, respectively.

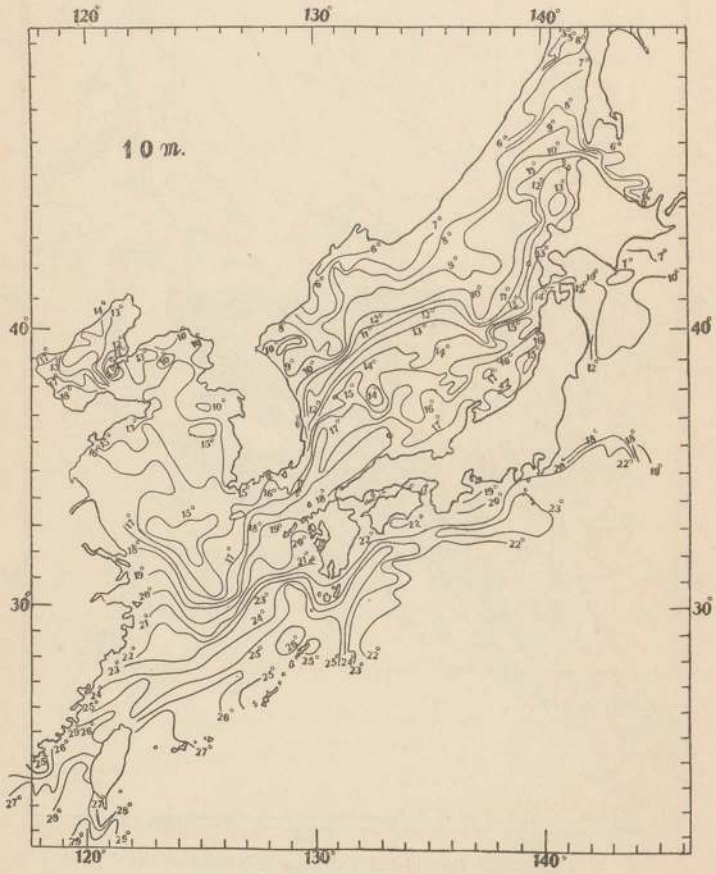


Fig. 7. Water Temperature at 10 m. Depth.
(Early June, 1932.)

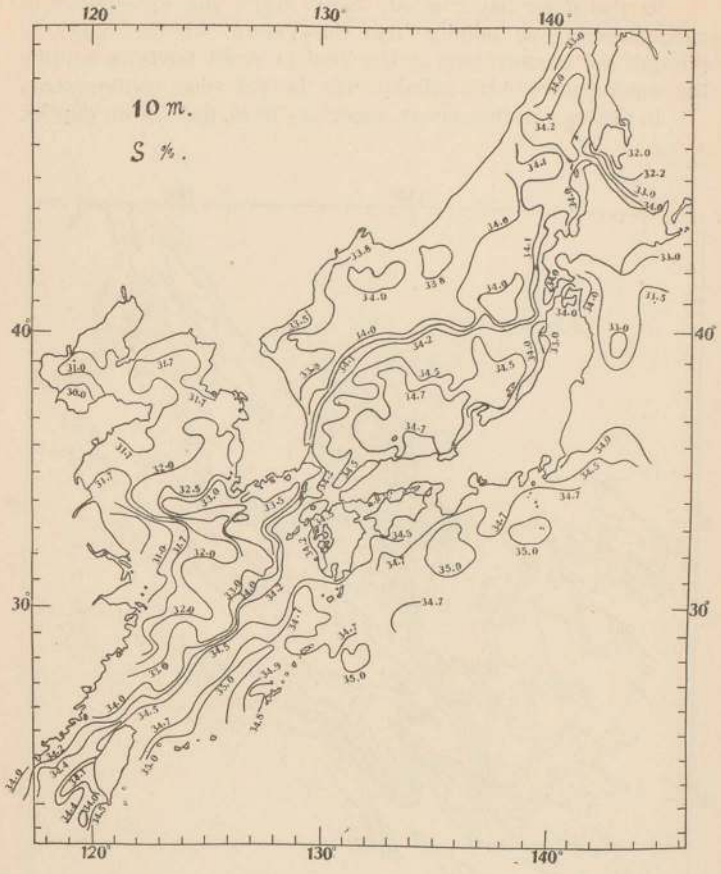


Fig. 8. Salinity at 10 m. Depth.
(Early June, 1932.)

From the above figures, we conclude that

(1) Since the Tusima Strait forms the threshold between the Pacific Ocean and the Japan Sea, it separates the water so characteristic of the lower layer of the Japan Sea from the exterior seas.

In the upper layer above 25 m. depth, the water-mass of comparatively low salinity from the Yellow Sea that flows in through the western part of the Tusima Strait tends to replace the water-mass of high salinity from the Kurosiwo water-system.

In the intermediate layers, especially 50 m. and 100 m. depths,

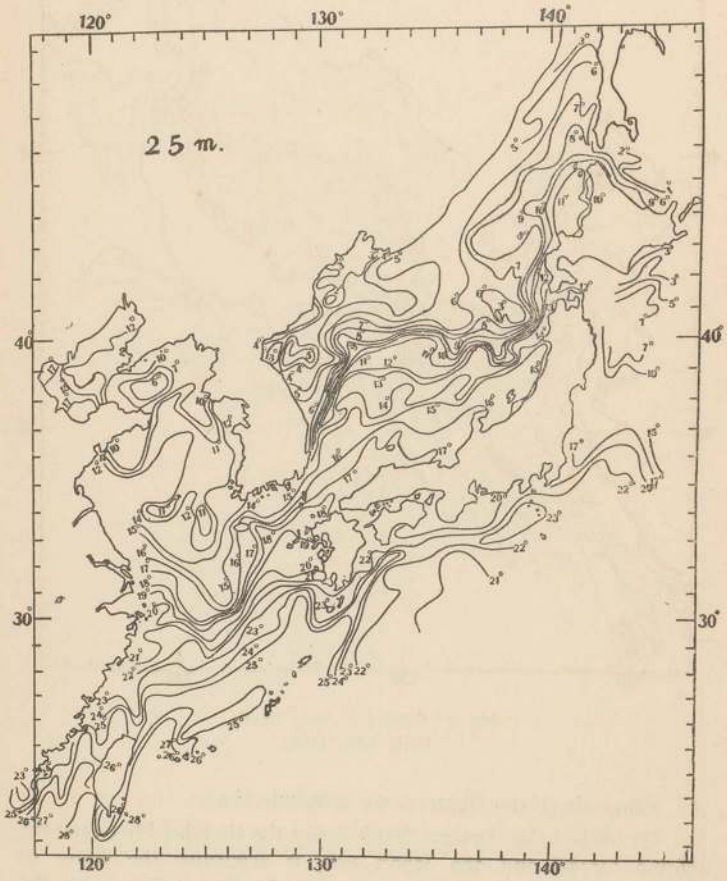


Fig. 9. Water Temperature at 25 m. Depth.
(Early June, 1932.)

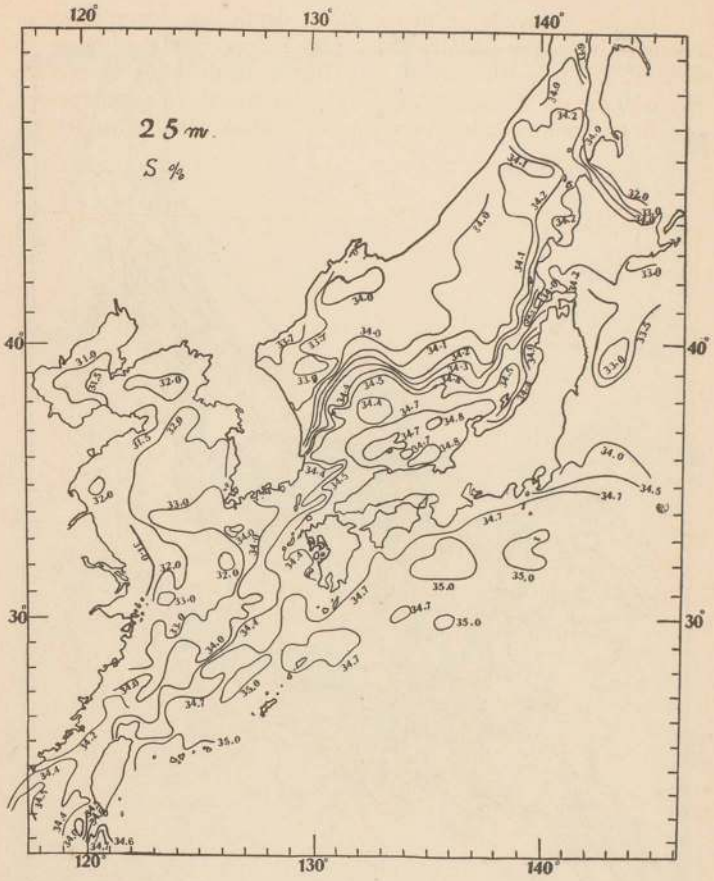


Fig. 10. Salinity (‰) at 25 m. Depth.
(Early June, 1932.)

the influence of the fresh water is not felt, with the result that the connection between the water-masses of high salinity lying both north and south of the Tusima Strait remains intact. In the bottom layer the connection with the salty water is clearly recognized.

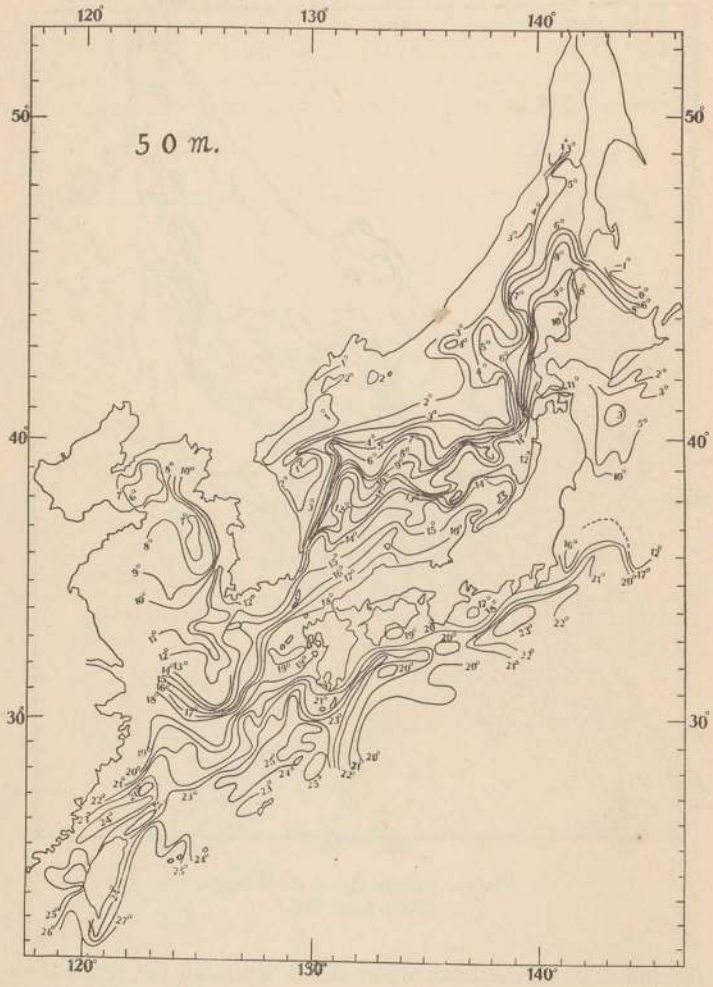


Fig. 11. Water Temperature at 50 m. Depth.
(Early June, 1932.)

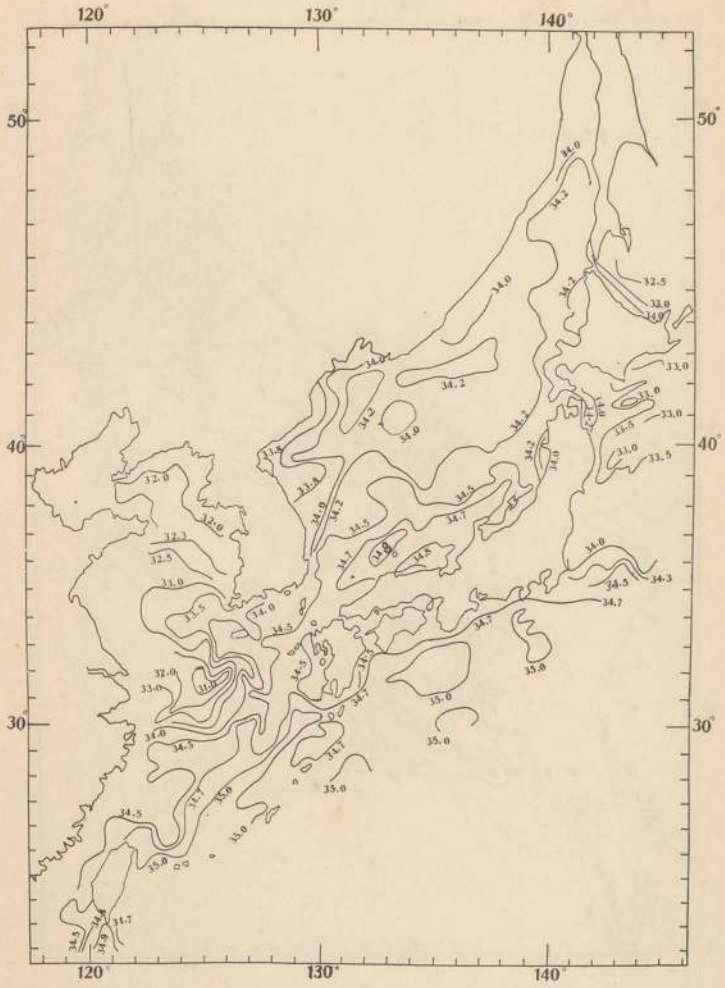


Fig. 12. Salinity (‰) at 50 m. Depth.
(Early June, 1932.)

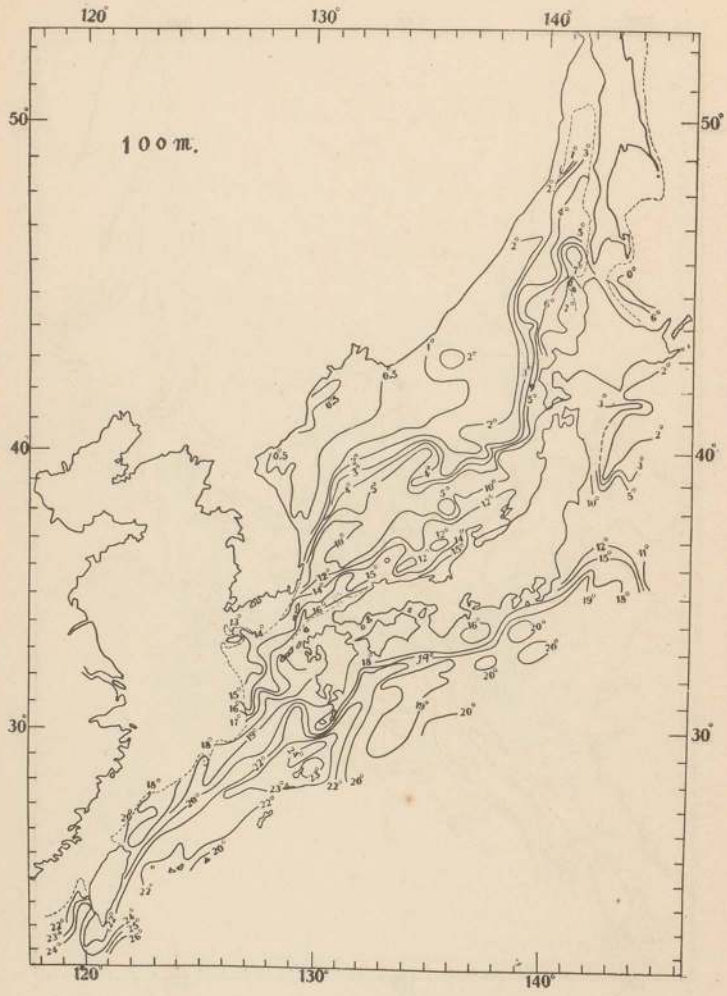


Fig. 13. Water Temperature at 100 m. Depth.
(Early June, 1932.)

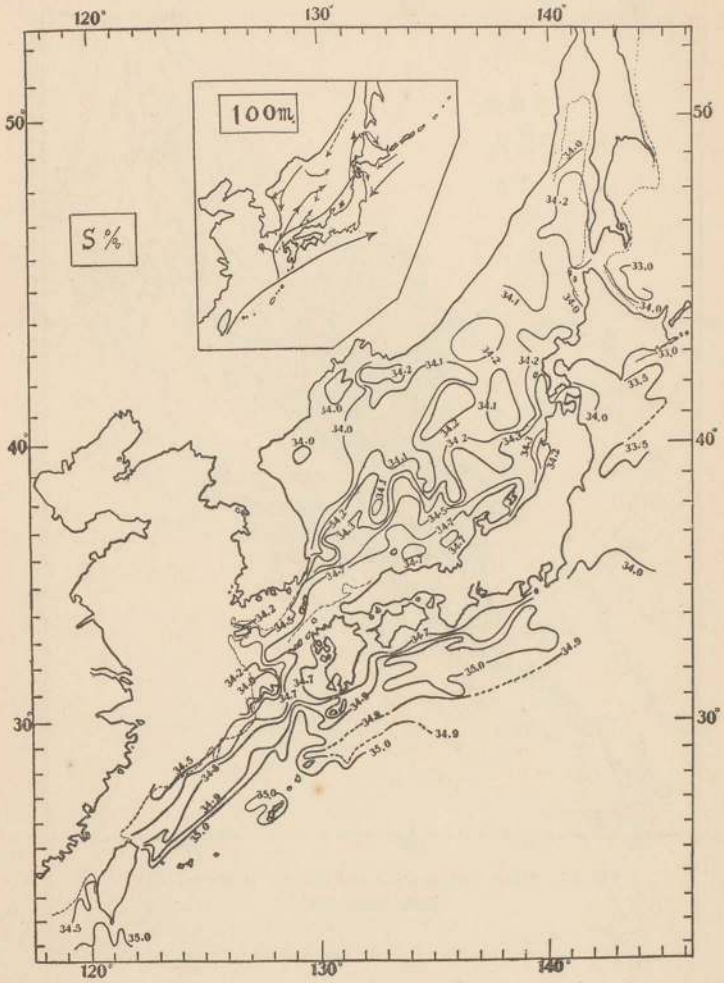


Fig. 14. Salinity and Inferred Current-Systems at 100 m. Depth.
(Early June, 1932.)

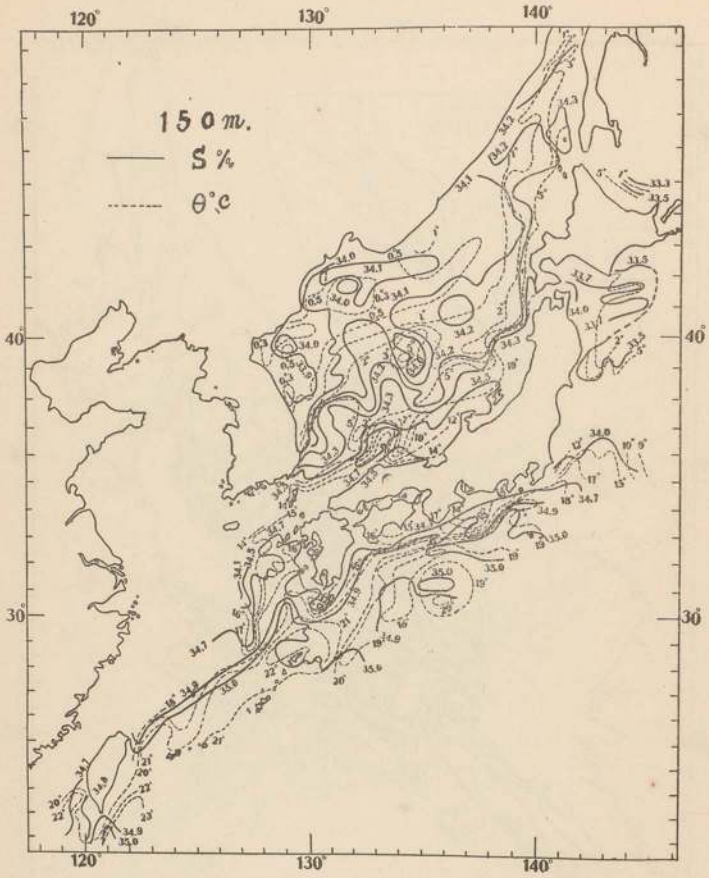


Fig. 15. Water Temperature and Salinity at 150 m. Depth.
(Early June, 1932.)

Although Tusima Strait is less than 150 m. deep, the salty water-masses are still observable in the layer 150 m. deep, north and south of the Strait, probably because the mixing of the waters take place actively to about this depth.

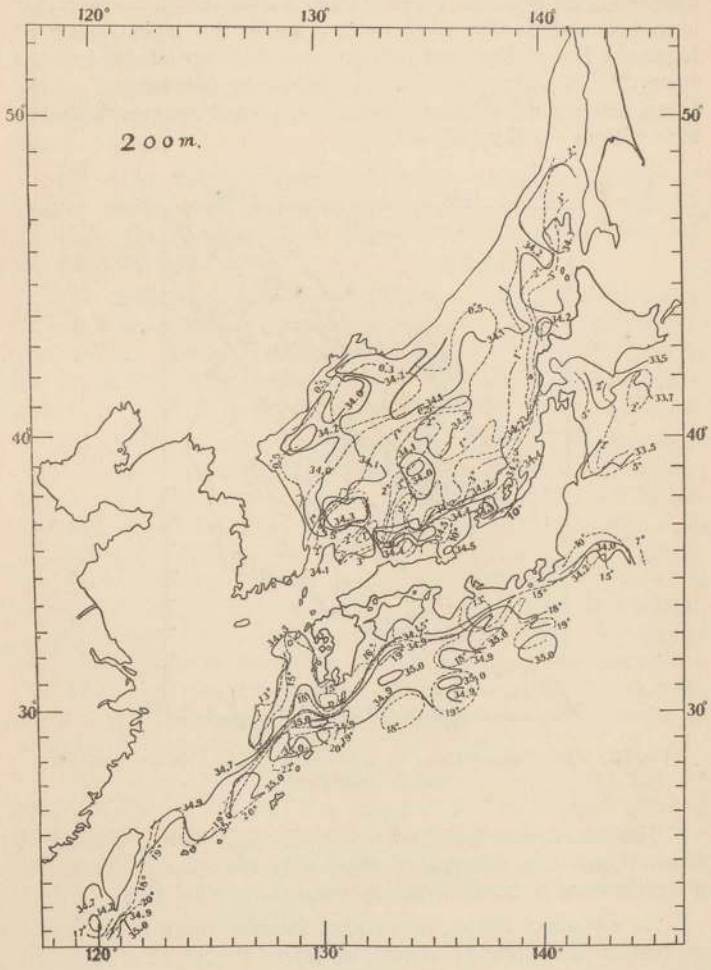


Fig. 16. Water Temperature (°C) and Salinity (‰) at 200 m. Depth.
(Early June, 1932.)

At a depth of 200 m., an abrupt discontinuity in the water-masses lying inside and outside of the Tusima Strait occurs; that is to say, whereas the water-mass lying in the region south of Nagasaki has a high temperature and salinity (above 15° and above 34.5 ‰ respectively), that forming the greater part of the Japan Sea has a low temperature (0°–2°C) and comparatively low but uniform salinity (34.0–34.2 ‰).

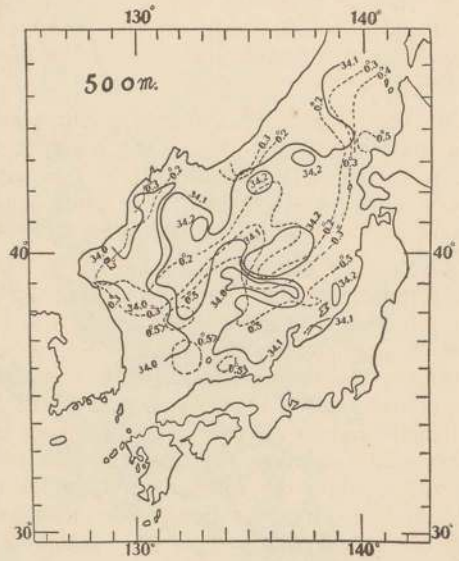


Fig. 17. Water Temperature (°C) and Salinity (‰) at a Depth of 500 m. (Early June, 1932.)

The water-mass that is distributed zonally along the coast of Japan Proper to a distance of about fifty sea-miles outward has a temperature of 5°–10°C and a salinity of 34.2–34.5 ‰.

At a depth of 300 m., too little of the water-mass of the warm current-system along the coast of Japan Proper remains to be detected. In contrast to the warm and salty water-mass, with a temperature above 14° and a salinity above 34.5 ‰, that is found south of Nagasaki, the water-mass in the Japan Sea is of low temperature (0°–2°) and of nearly uniform salinity (34.0–34.2 ‰).

The facts above mentioned may be explained by supposing that the thickness of the warm water-mass of the Tusima Current, flowing in from the south as a branch of the Kurosiwo, which at the Tusima Strait (threshold) extends to a depth of 100 to 150 m., increases after it crosses into the Japan Sea to from 150 to 200 m., owing to the turbulence caused by the mixing of the waters there.

(2) Cold water is observed welling up in the vicinity of several capes, such for example, as the Nisinotoro Misaki, Busuitan, the promontory of Ryôtô Peninsula, Santô Cape, and the end of Zenra Nandô.

(3) In the seas off northern Tyôsen, along the boundary zone of two water-masses, cold and warm, with salinity more and less than 34.1 ‰ respectively, and corresponding to the polar front in the Japan Sea, several water-masses, warm and cold, exist alternately, probably as the result of vortical currents on a small scale.

(4) West of Cape Tirai (Karahuto) on the Siberian side, water mass of low temperature and salinity (the lowest 3.4°,33 ‰) was found. The inference is that it belongs to the so-called Liman-Current, which originates in the Kokuryû-Kô, although it is difficult to imagine that the Liman-Current, flowing south, ultimately forms the main part of the cold water of North Tyôsen. It is possible, though, that a small part of the cold water in question, in descending southward along the Siberian coast and mingling with the counter-current that forms a branch of the north-going Tusima Current in the northern part of the Japan Sea, may become a part of the cold water of North Tyôsen. Evidence in support of this possibility will be given later.

(5) Along the continental shelf of the East China Sea, we clearly observe a remarkable discontinuity of salinity (also of temperature), that is, a sharp boundary between the water of the China Sea and the Kurosiwo-water. We see also that the cold bottom water of the Yellow Sea flows south towards the discontinuity line mentioned above.

(6) East of the Yellow Sea and Pwok Hai, the salinity is higher than in the west. In the seas in the northern and western end of Pwok Hai and those along Central China, the salinity is very low, less than 30 ‰. The reason for this in the former is probably due to the inflowing of the rivers, Kôga (Yellow R.),

Pei Ho, Ryôga (Liau Ho) etc. and in the latter to those of the rivers Yangtse Kiang, etc.

As to the sea-currents, a branch of the warm Kurosiwo current flows northward east of the Yellow Sea. On the other hand, a current conveying water of low salinity from the mouth of the Yangtse Kiang, the volume of which increases remarkably with the monsoon rains, extends eastward as stratification develops with rise of surface temperature, as far as the western entrance of the Tusima Strait, drawn in there by the action of the counter-clockwise vortical current. The inflow is greater in summer.

(7) The main water-mass belonging to the cold current-system in the Japan Sea is found localised in the North Tyôsen sea region. The central axis of the North Tyôsen Cold Current extends from the seas off Kankyô-Hokudô to the seas off Kôgen-Dô, about fifty sea-miles distant from land in a SE direction.

(8) The water layers at depths of 0 m., 10 m., and 25 m. show nearly uniform property. In particular, the isotherms and isohalines in the layer at 10 m. depth indicate the typical trend of the upper layer.

At depths of 50 m. the general trend of isolines exhibits features of intermediate water, while branches of cold water are found invading the warm water to some extent.

The isotherms and isohalines at layers of 25 m. and 50 m. depths show conspicuous horizontal gradients, the boundary between the cold and warm water-masses being quite obvious. The maximum temperature gradient in the horizontal direction was observed in two regions, one nearly west of the Tugaru Strait, with 3°–5°C per 10 sea-miles, and the other east of the Geizitu Wan, with 3°–5°C per 10 sea-miles.

Since a discontinuity layer lies between depths of 100 m. and 200 m. (that is, a zone of transition from the base of the upper water of the warm current-system to the cold water peculiar to the Japan Sea at depths), the discontinuity layer is liable to move up and down as the result of external disturbances, thereby introducing a conspicuous horizontal variation in the iso-lines, with consequent important results on the living conditions of the bottom inhabitants and the fishes in the intermediate layers.

As we descend from 150 m. to 200 m. and from 200 m. to 300 m., a closer correlation between the isotherms and the bathy-

metric lines is observed, while isolated warm water-masses are observed on several banks.

In the seas off Simane, a peculiar feature, common to layers of from 150 m. to 400 m. deep is the appearance of water of comparatively low salinity, belonging to the cold current-system, which comes from the seas off Keisyô-Hokudô after proceeding in a SSE direction beneath the regions of the Tusima Current-

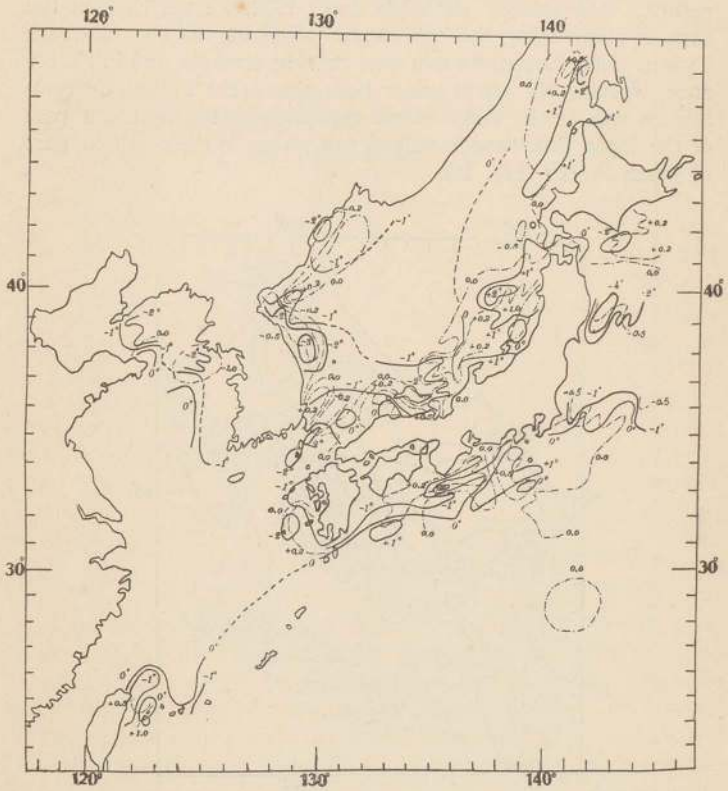


Fig. 18a. Anomalies of Water Temperature (—— °C) and Salinity (----- ‰) at the Surface.
(Early June, 1932.)

System. This phenomenon may be regarded as indicating a general cyclonic circulation of the cold lower waters of the Japan Sea.

Below 400 m., the water-mass shows almost uniform property with small horizontal variation.

VII. Anomaly in Horizontal Distribution of Water Temperature and Salinity.

Upon plotting the isallo-curves of anomalies of water temperature and salinity for early June, 1932, we see that, at the time of observation, the cold water belonging to the Northern Tyôsen Cold Current-System was flowing strongly and in abundance, whereas the warm water belonging to the Tusima Current-System was in the very reverse condition in the southern part of the Japan Sea, though still in full swing in the northern part of Japan Proper (Fig. 18).

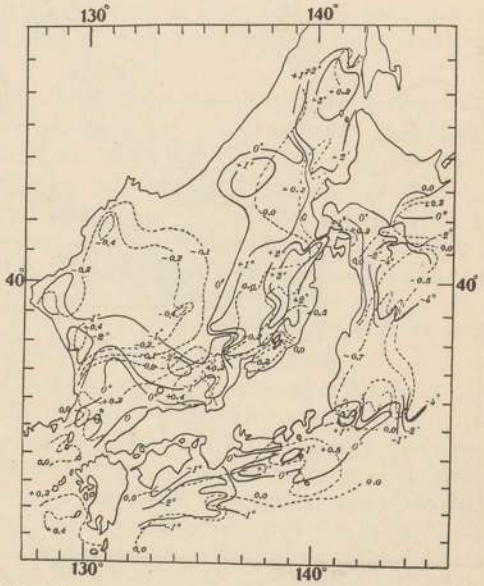


Fig. 18b. Anomalies of Water Temperature (—— °C) and Salinity (------ ‰) at the Depth of 100 m. (Early June, 1932.)

The branch of the warm current that flows in to the Yellow Sea was also flowing feebly and in small volume at that time.

VIII. Vertical Distribution of Water Temperature and Salinity.

The vertical distribution of water temperature and salinity at a number of representative stations are shown in Fig. 19.

From Fig. 19, we can distinguish two types of vertical distribution, namely, the cold water type (northern) and the

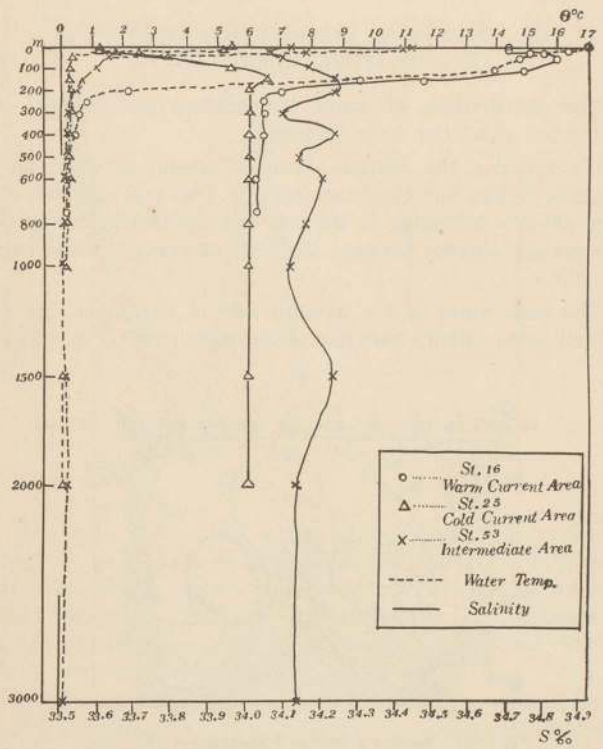


Fig. 19. Vertical Distribution of Water Temperature and Salinity.

warm water type (southern). We can see also that in the layer that is deeper than 200 m., the distribution is nearly uniform, whereas above 150 m. there is considerable variation.

In the Yellow Sea, water layers with spring temperatures are frequently observed in summer. A notable instance is the following:

June 8, 1932. (12h.)	Depth (metre)	0	5.4	6.4	7.3	10	25	43 (bm.)
39°12′ N.	Water Temp. (C°)	15.5	15.0	12.7	8.8	8.8	8.7	8.6
127°37′ E.	Salinity (‰)	29.79	—	—	31.49	31.78	31.69	31.69

("Hisyun Maru")

IX. Sectional Distribution of Water Temperature and Salinity.

The distributions of water temperature and salinity were investigated at all the cross sections.

We find that the Tusima Warm Current, on entering the Japan Sea, divides into two branches (Fig. 20a) and also that water of low salinity belonging to the cold current-system creeps along the boundary surface between the cold and warm water-masses (Fig. 20b, c, d).

The deep water in the western part of the Japan Sea is of relatively lower salinity than that of the eastern part (Fig. 20b, c, d).

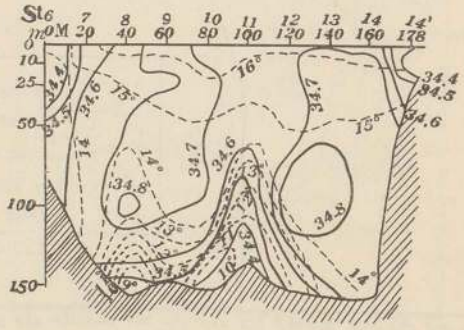


Fig. 20a. Section of Water Temperature (θ °C) and Salinity (S ‰) from Simonoseki to Husan. (May 11, 1932).

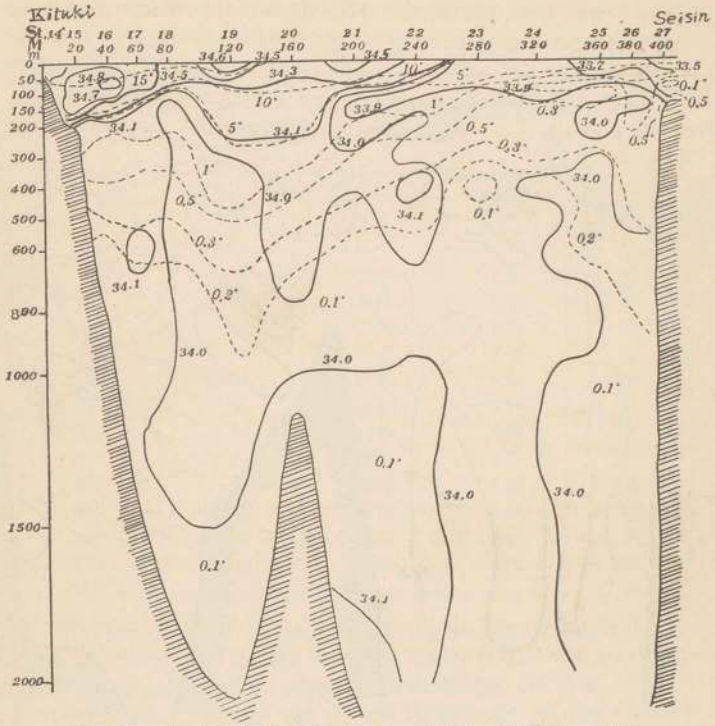
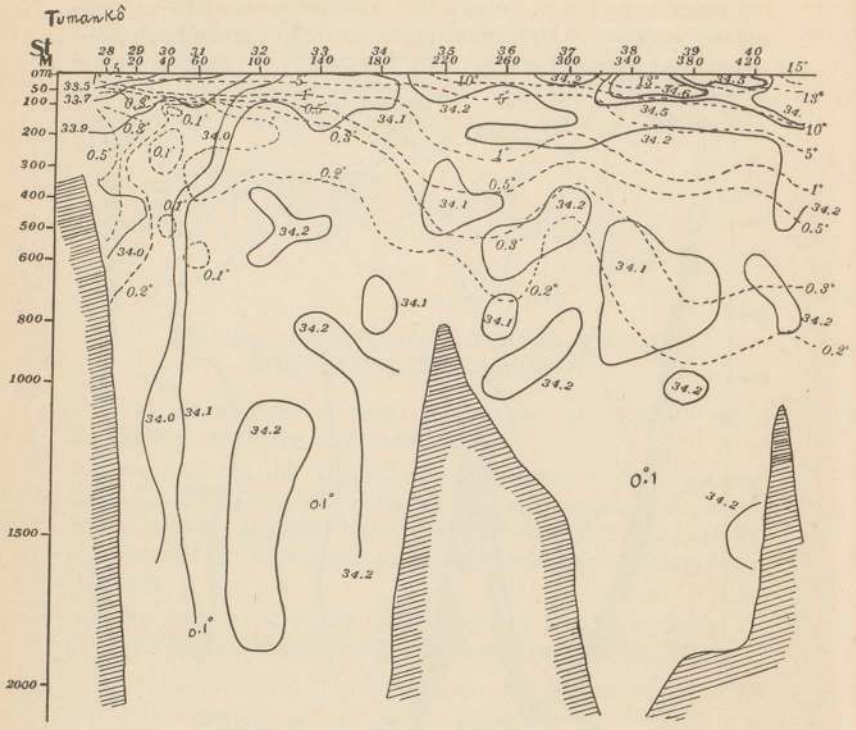


Fig. 29b. Section of Water Temperature (θ °C) and Salinity (S ‰) from Kituki to Seisin. (May 16—18, 1932.)

The lower cold water in the Yellow Sea (temperature less than 8° C), which extends from 35° N to 37°30′ N. The boundary layer between the upper warm water the lower cold water lies at about 25–50 m. depth, being shallower in the northern seas than in the southern, and in the central part of the sea-basin than in the coastal regions.

It may be added here that according to the observations of the "Misago Maru"[6] (Tab. 4), in the sea south-west of Kyûsyû, the upper layer above 75 m. depth, is comparatively fresh ($S<34.5$ ‰), owing to the influence of the China Sea, but at 100 m.,



Eig. 20c. Section of Water Temperature (ϑ °C) and Salinity (S ‰) from Tumankô to Sado. (May 21—23, 1932.)

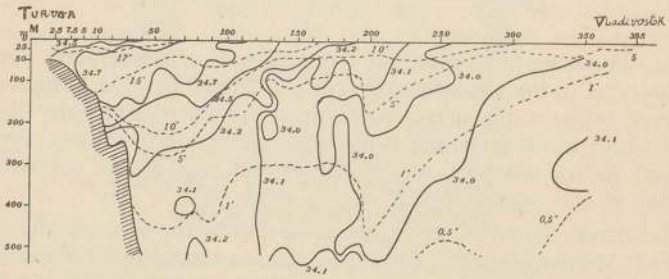


Fig. 20d. Section of Water Temperature (ϑ °C) and Salinity (S ‰) from Turuga to Vladivostock. (VI. 6—8, 1932). (Hukui Fish. St.)

the water suddenly becomes salter, the layer between 150 m. and 200 m. being of the highest salinity above 34.7 ‰ in the Kurosiwo-water.

Table 4. Observation by "Misago Maru" at (129°21′ E, 31°55′ N).

Depth \ Term	Salinity S ‰	Water Temp. θ °C	Dissolved Oxygen O_2 cc.	Percentage Saturation of Oxygen %
m.				
0	34.23	19.80	5.26	97
10	36	19.69	5.29	98
25	31	19.56	5.27	94
50	27	18.61	5.20	94
75	25	17.83	5.22	93
100	52	16.58	4.78	84
150	72	15.86	4.86	84
200	70	15.17	4.70	81
300	58	13.02	4.03	66
400	43	11.54	3.64	58
600	34	6.88	2.43	36
818 (bm.)	36	6.04	2.01	29

Further down at a depth of 300 m., an abrupt transition is again observed, and in the layer at about 600 m.–800 m. depth, the so-called intermediate water of Pacific Ocean (34.35 ‰, 6°–7°C) is in evidence. West of the sea off Kumamoto, on the slope of the continental shelf, is a zone of from about 100 m. to 200 m. depth. Along this zone, the Kurosiwo-water and the water of the China Sea are in contact with each other, where an intensive mingling in the form of an intricate distribution of warm (salty) and cold (relatively fresh) water-masses, was discovered through sectional observations made by the "Higo Maru" "Hatutaka Maru", and "Hisyun Maru".

X. Distribution of Water Temperature and Salinity in the Longitudinal Cross Sections.

With the purpose of studying longitudinal cross sections of the Japan Sea, representative stations were selected as shown in

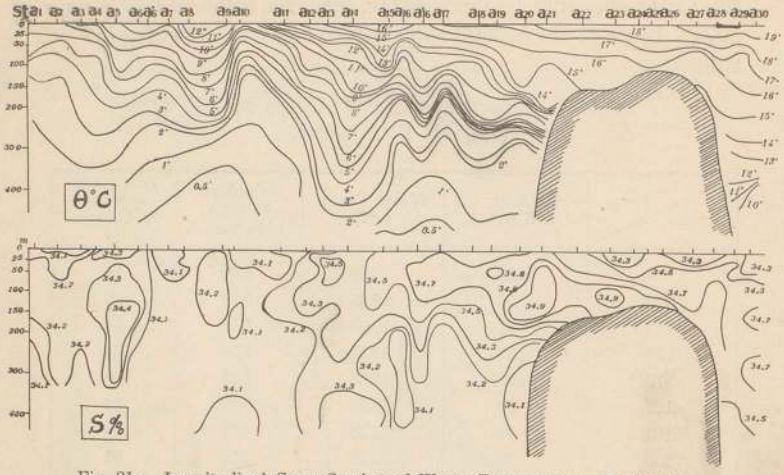


Fig. 21a. Longitudinal Cross Section of Water Temperature and Salinity along Japan Proper (a-Line). (About June 5, 1932.)

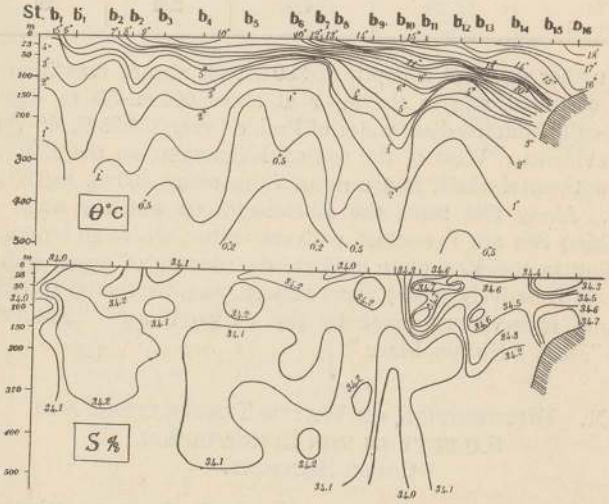


Fig. 21b. Longitudinal Cross Section along the Central Line of Japan Sea (b-Line). (Early June, 1932.)

Fig. 1, besides three longitudinal cross sections along lines joining these stations, one along Japan Proper, another along the central line of the Japan Sea, and a third along the continental side (Fig. 21).

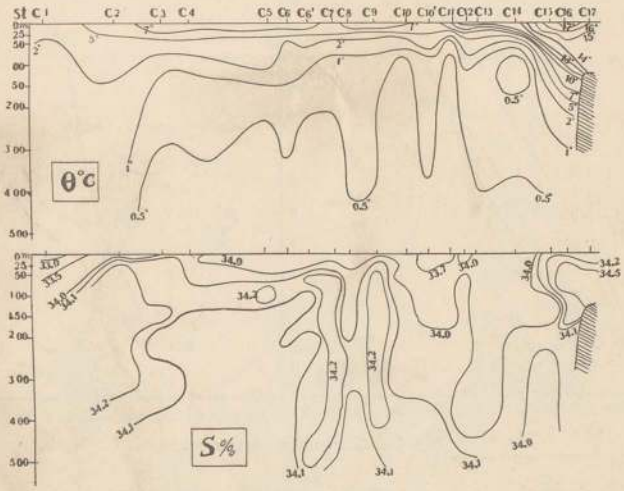


Fig. 21c. Longitudinal Cross Section along the Continental Side (c-Line). (Early June, 1932.)

From these sectional figures we see that a comparatively warm and salty water-mass sinks into the western seas off Karahuto, and that the characteristic cold water of the Japan Sea wells up in the seas off Esasi in Hokkaidô and also west of Tugaru Strait to the 100 m.-depth layer. We also see that the water-mass of highest salinity in the Japan Sea ($S>34.7$ ‰) extends from the seas off Niigata to the Tusima Strait and also that the layers having the highest salinity lie at greater depths as we go south.

XI. Thermohaline Curve.

The thermohaline curves for the stations (Fig. 22), may be classified into three typical forms, namely, the northern cold water type, the southern warm water type, and the intermediate type.

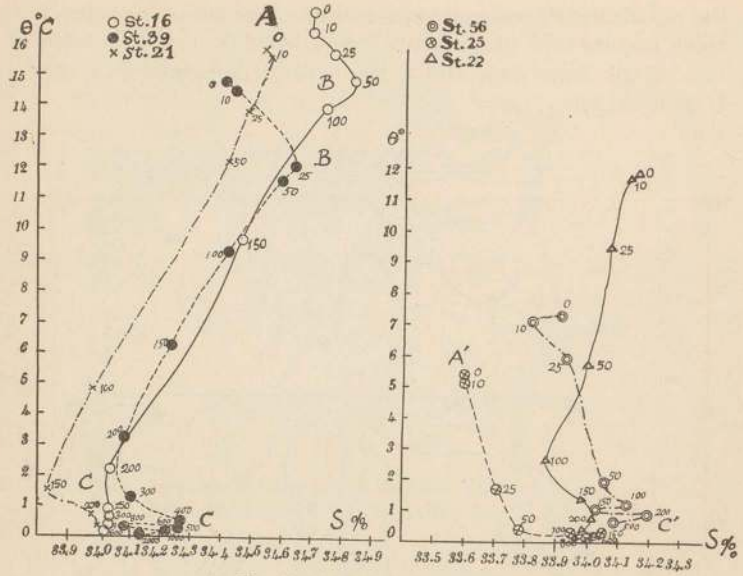


Fig. 22. Thermohaline Curves.

The fundamental water-masses are; (1) the water-masses in the upper and lower water layer, subject to the influence of the northern cold current-system A′ and C′, respectively, (2) the water-masses in the upper and intermediate water-layers belonging to the southern warm current-system A and B; and (3) the cold water peculiar to the Japan Sea, C.

XII. Geographical Distribution of Water Colour and Transparency in Early June, 1932 (Fig. 23).

The water colour was determined by Forel's scale and the transparency measured by Secchi's disc of 30cm. diameter, painted white.

On the whole, the distribution of water colour agrees well with that of transparency. Both resemble the distribution of salinity in the upper layer above 50 m. depth. In the Japan Sea,

the northern cold water-area is a turbid area with transparency value less than 10 m., its water colour being V of Forel's scale.

But the southern warm water-area is a transparent area with a transparency value of 15–25 m. and of water colour II~III of Forel's scale. An intermediate zone, having a transparency of

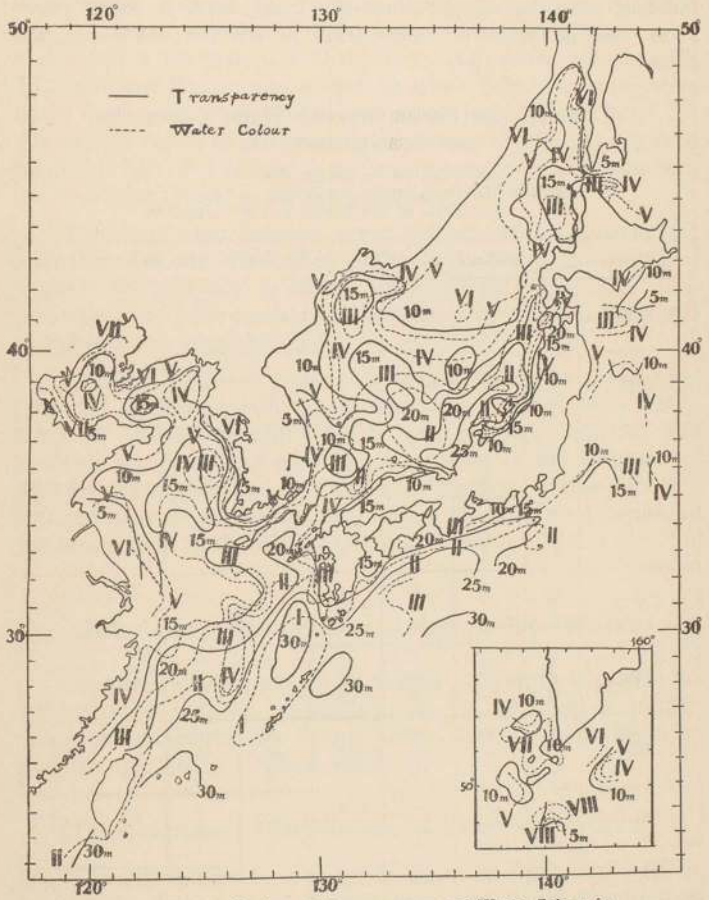


Fig. 23. Distribution of Transparency and Water Colour in Early June, 1932.

10–15 m. and water colour IV of Forel's scale, lies between these two areas. In the coastal water-area along Japan Proper, from Akita Prefecture to Simane Prefecture, the transparency is 10–15 m. and the water colour IV–V. The highest transparency is found in the water-area of the main Tusima Current-System, which extends from the sea off Akita to the sea off Hyôgo, about a hundred sea-miles distant from the coast, with a value above 25 m., the maximum of 35 m. being in the sea north of Sado Island.

Table 5. Correlation between Water Colour (F) and Transparency (D).

Notice: A—Freq. in the Pacific side.
B—Freq. in the Japan Sea.
C—Freq. in the Yellow Sea & China Sea.

F \ D		0–5 m.	6–10 m.	11–15 m.	16–20 m.	21–25 m.	26–30 m.	31–35 m.
>VIII	A	—	—	—	—	—	—	—
	B	2	—	—	—	—	—	—
	C	5	—	—	—	—	—	—
VIII	A	3	—	—	—	—	—	—
	B	—	—	—	—	—	—	—
	C	2	—	—	—	—	—	—
VII	A	—	9	1	—	—	—	—
	B	—	3	—	—	—	—	—
	C	4	1	—	—	—	—	—
VI	A	—	4	3	—	—	—	—
	B	12	18	—	—	—	—	—
	C	4	8	1	—	—	—	—
V	A	1	6	6	1	—	—	—
	B	2	33	30	2	—	—	—
	C	1	22	6	3	—	—	—
IV	A	1	7	14	7	3	—	—
	B	1	22	65	24	2	—	—
	C	—	6	22	9	—	—	—
III	A	—	3	9	22	10	8	—
	B	—	7	28	45	18	1	2
	C	—	3	7	8	2	1	—
II	A	—	—	3	5	6	10	3
	B	—	—	2	12	6	7	—
	C	—	—	—	2	1	—	—
I	A	—	—	—	—	6	4	4
	B	—	—	—	—	—	—	—
	C	—	—	—	—	—	—	—

As is well known, the neritic water in the East China Sea, Yellow Sea, and Pwok Hai are very turbid, with a transparency value of less than 10 m. and of water colour V–VI, Forel's scale. In fact, the lowest transparency at the head of Pwok Hai is less than 5 m. and its water colour paler than VI. The central part of the Yellow Sea has a water-mass of transparency 10–15 m. and water colour of about IV. The area outside of the 100 m. isobathymetric line corresponds to the transparent Kurosiwo water-area, which has a transparency of 15–35 m. and water colour I–III. The northern Pacific side of the Oyasiwo Cold Current-System has a transparency of 5–10 m. and water colour paler than IV. The muddy colour of the water (transparency about 5 m.) observed by the Hokkaidô Fisheries Experimental Station in the southern sea of Camtchatska is worthy of notice.

The correlation between water colour and transparency is shown in Tab. 5. The colour of the China Sea is pale compared with its transparency, in which it differs from other seas. It is probably due to the turbidity of inorganic yellowish mud-particles brought down from the land.

The comparatively transparent area in the North Tyôsen sea (Fig. 23), combined with the presence of a relatively salty water-mass in the subsurface layer of this region, is curious and presents an interesting problem. According to the estimate of Mr. H. AIKAWA on the distribution of plankton in this district,[13] the fact that they consist chiefly of zoo-plankton, may furnish an important clue to the solution of this problem.

XIII. CHEMICAL INVESTIGATIONS OF SEA WATER.

Dissolved oxygen and its percentage saturation, hydrogen ion concentration, silicate, phosphate, and the nitrogen as nitrate, were determined by the "Sôyô Maru" and "Misago Maru",[6] and the oxygen by "Hukui Maru".

(1) Horizontal Distribution of Dissolved Oxygen.

The distribution of oxygen in layers at 0 m., 50 m., 100 m. and 200 m. depths (Fig. 24) agree well with the distribution of water temperature and salinity. The area rich in dissolved oxygen

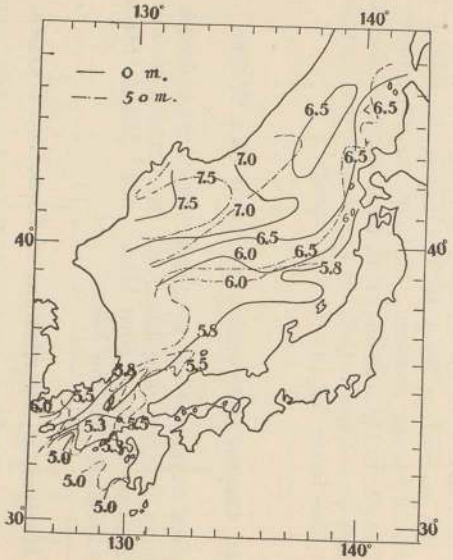


Fig. 24a. Dissolved Oxygen O_2 cc/lr. at the Surface and at a Depth of 50 m.

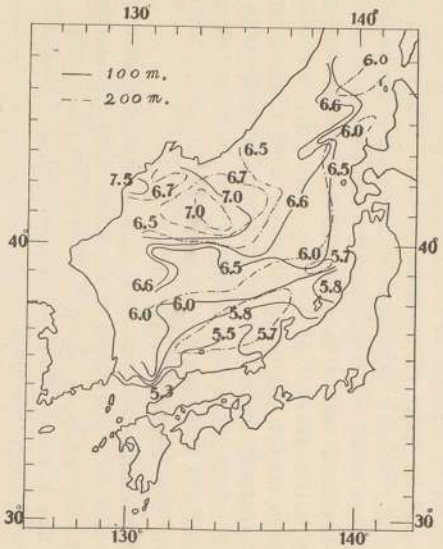


Fig. 24b. Dissolved Oxygen O_2 cc/lr. at a Depth of 100 m. and of 200 m.

corresponds to the area of low temperature and salinity, and conversely, the area poor in dissolved oxygen corresponds to the area of high temperature and salinity.

(2) Sectional Distribution of Dissolved Oxygen. (Fig. 25).

The source of supply for the richly dissolved oxygen in the Japan Sea is traceable to the cold water-area, and the area of richly dissolved oxygen may be inferred to extend from north to south in a deeper layer.

The oxygen dissolved in the deeper layer beneath depths of 400 m.–600 m. in the northern cold water-area seems to be poorer than that of the southern seas at the same level. It suggests an ascending current in the northern deep water.

On the section from Huzan to Hinomisaki, we find at the central part in the layer between the 50 m. depth and the sea-

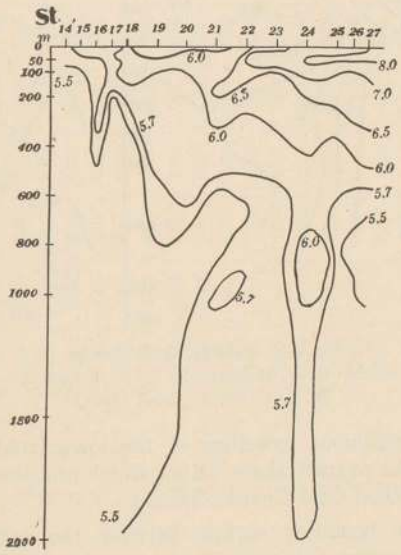


Fig. 25a. O_2 cc/lr. in the Section from Kituki to Seisin. (Sôyô Maru).

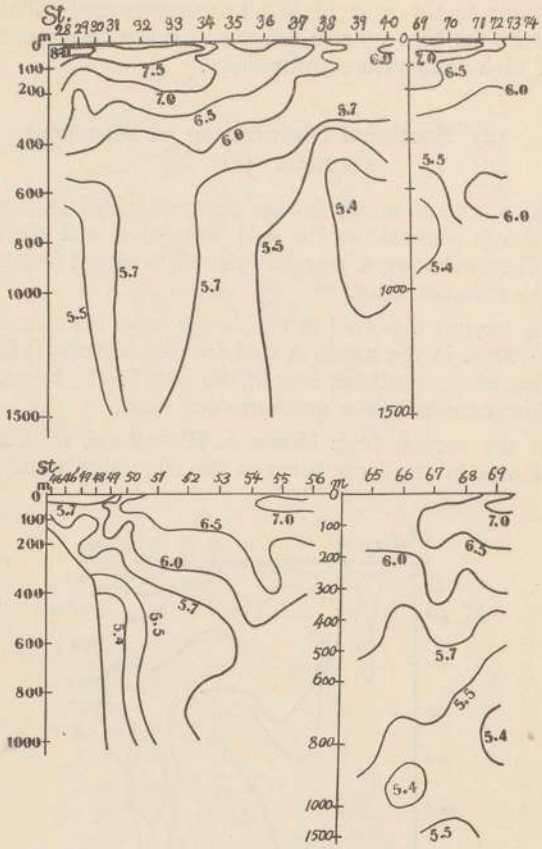


Fig. 25b. O_2 cc/lr. ih the Section
(Tumankô—Sado), (Niigata—St. A), (C. Kamoi—St. B),
(St. B—C. Sôya). (Sôyô Maru.)

bottom, a conspicuous upwelling of the lower cold water, with richly dissolved oxygen above 5.8 cc., which probably comes from the North Tyôsen Cold Current-System.

Along the boundary surface between the cold and warm water-masses, water rich in dissolved oxygen creeps down beneath the water of warm current-system (Fig. 25).

Table 6. Dissolved Oxygen (cc/litre) from Serial Observation of the Depth above 1000 m. by "Sôyô Maru".

St. \ Depth (m.)	0	10	25	50	100	150	200	400	600	800	1000	1500	2000	3000
17	5.82	5.82	**6.07**	5.84	5.76	5.97	*5.45*	*5.45*	*5.45*	*5.45*	*5.45*	*5.45*	(1300m.)	—
19	5.99	5.99	5.94	**6.18**	5.97	5.92	5.92	5.89	5.55	5.50	*5.42*	5.47	5.53	—
21	5.84	5.97	6.10	5.92	6.28	**6.59**	6.28	5.79	*5.47*	*5.47*	(5.92)	5.55	5.55	—
22	6.34	6.46	**7.03**	6.98	6.72	6.18	6.10	5.71	*5.50*	—	5.60	5.60	5.60	—
23	6.93	6.95	7.21	**7.37**	6.41	6.31	6.20	5.89	5.66	5.63	5.60	*5.53*	5.55	—
24	7.11	7.16	**8.04**	7.58	7.27	6.85	6.51	6.05	5.82	(6.75)	(6.20)	5.73	5.71	—
25	7.94	8.02	**8.12**	7.86	7.01	6.83	6.69	5.79	5.55	*5.50*	5.55	5.55	5.55	—
26	7.86	7.89	**8.08**	7.47	6.95	6.85	6.77	6.38	5.58	*5.50*	*5.50*	5.58	5.55	—
29	7.62	—	**8.17**	7.26	6.94	6.55	6.33	6.08	5.51	*5.48*	*5.48*	*5.48*	—	—
32	7.34	—	7.62	**7.81**	7.23	7.07	6.88	5.75	5.75	5.78	*5.73*	—	*5.73*	*5.73*
34	7.03	—	**7.57**	6.45	7.24	7.13	7.03	6.18	5.69	5.69	5.69	*5.56*	—	—
39	5.94	—	5.94	5.80	5.88	**5.96**	5.88	5.50	*5.36*	*5.36*	5.39	5.42	—	—
40	5.96	—	6.02	5.85	5.85	**6.15**	5.80	5.56	*5.39*	*5.39*	*5.39*	5.45	—	—
42	**6.10**	—	5.75	5.80	5.85	5.75	5.91	5.83	*5.39*	5.42	5.42	5.55	—	—
49	5.61	—	6.25	5.92	**6.37**	**6.37**	5.67	5.39	*5.33*	*5.33*	*5.33*	5.36	—	—
51	6.20	—	**6.98**	6.76	6.56	6.48	6.34	5.58	5.56	5.67	*5.50*	5.53	5.53	—
53	7.06	—	**7.43**	6.79	6.81	6.34	6.25	5.75	5.67	5.72	5.72	—	*5.53*	*5.53*
68	6.37	—	**6.70**	6.59	6.53	6.14	6.00	5.92	5.53	*5.47*	*5.47*	5.53	(1400m.)	—
69	6.98	—	**7.54**	6.59	6.84	6.84	6.37	5.64	5.42	*5.36*	5.47	5.42	—	—
70	6.65	—	**7.40**	6.65	6.14	6.42	6.14	5.75	5.53	*5.47*	*5.47*	*5.47*	(1450m.)	—

(3) Vertical Distribution of Dissolved Oxygen
(Tab. 6, Fig. 26a).

The quantity of dissolved oxygen in the upper layer above a depth of 200 m. is abundant, with maximum at depth of 25 m.–50 m.

The depth of maximum dissolved oxygen lies at a comparatively shallower level in the cold water than in the warm water, but it varies from station to station. In the warm water-area the vertical difference in the dissolved quantity of oxygen is relatively small compared with that in the cold water-area. From Table 5 it will be seen that an intermediate minimum of dissolved

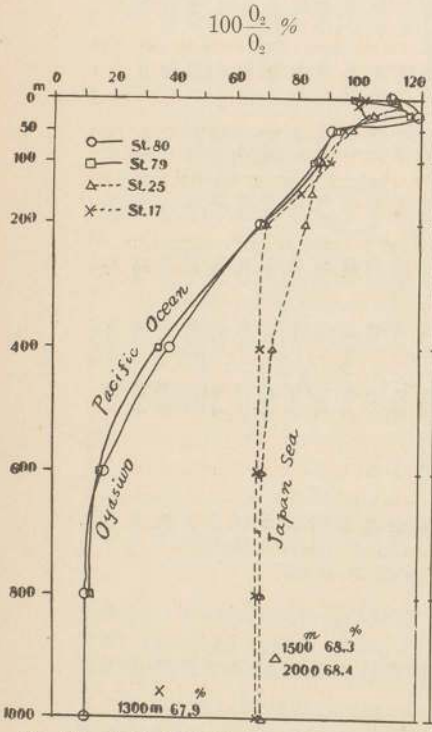


Fig. 26b. Vertical Distribution of Percentage Saturation of Dissolved Oxygen.

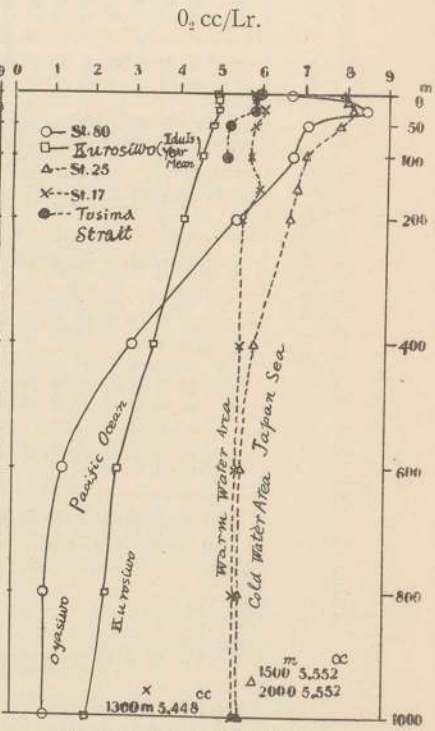


Fig. 26a. Vertical Distribution of Dissolved Oxygen.

oxygen frequently occurs at depths of about 800 m.–1000 m. In other words, 13 out of the 20 stations (or 65 %), where depths above 1000 m. have been observed, showed, though sometimes feebly, intermediate minima of oxygen, while at the remaining 7 stations a continuous decrease of dissolved oxygen with increase of depth was observed. The most conspicuous intermediate minimum value of dissolved oxygen is seen at St. 39–49 (seas adjacent to Sado Island) with a value of 5.3–5.4 cc/1 r.

(4) Percentage Saturation of Dissolved Oxygen $(100 \frac{O_2}{O_2'})$ %.

(a) Horizontal Distribution. From the distribution at the layer 25 m. deep, we see that stations in the greater part of the Japan Sea are supersaturated, except that area along Japan Proper, fifty sea-miles distant from the coast, which shows deficiency of oxygen. This wide supersaturated area extends to the north-western part of the sea, the value being 105–110 % (Tab. 7).

(b) Sectional Distribution. The percentage of saturation in the deep water-layer of the Japan Sea beneath depths of 500 m. is nearly everywhere uniform with a value of 60–70 % (Tab. 7).

(c) Vertical Distribution. The percentage of saturation is maximum at a depth of 0 m.–25 m., being generally supersaturated. It seems to denote the depth at which the photosynthetic action of phyto-plankton occurs most actively, as a necessary result of which the excess of oxygen is produced. In the layer above 50 m. depth a slightly marked supersaturation is found in the cold water-area. Generally speaking, however, there is no marked difference in this feature between the cold and warm water-area, especially beneath depths of 500 m., where the percentage of oxygen saturation is nearly uniform, which is the most remarkable feature in the Japan Sea, and which provides important suggestions as to the origin of the deep water (Fig. 26b). Compared with those on the Pacific side, the dissolved quantities and the saturation percentages of oxygen of the two

Table 7. Percentage Saturation of Dissolved Oxygen (%). ("Sôyô Maru.")

St. \ Depth (m.)	0	10	25	50	100	150	200	400	600	800	1000	1500	2000	3000
16	100.7	101.9	104.3	95.2	90.8	101.3	75.2	71.3	67.1	66.1		—	—	—
17	101.2	99.4	101.9	95.2	90.1	80.7	70.0	67.9	67.3	67.3	67.3	67.9	(1300m.)	—
18	105.0	103.2	105.8	93.7	80.2	75.8	72.6	67.8	67.3	67.3	67.3	—	—	—
19	102.6	102.6	98.7	99.0	92.8	91.6	86.0	75.8	69.0	67.3	67.2	67.8	67.6	—
20	101.4	100.9	103.8	99.4	94.4	91.3	86.0	72.4	69.0	67.1	67.1	—	—	—
21	101.2	103.1	102.0	96.0	87.0	84.5	78.8	71.7	67.7	67.6	67.6	67.6	67.6	—
22	102.1	103.8	108.0	98.8	88.7	78.9	76.7	70.9	68.1	—	69.0	69.0	69.0	—
23	105.4	105.7	109.0	110.8	80.9	78.7	77.2	72.5	69.8	69.5	69.1	68.1	68.5	—
24	105.0	104.8	110.2	94.7	90.0	85.0	81.2	74.8	72.0	—	—	71.0	70.2	—
25	111.3	111.8	104.4	97.7	87.0	84.9	82.8	71.6	68.7	68.1	68.5	68.3	68.4	—
26	110.1	109.2	103.9	95.2	86.9	84.6	84.5	79.1	69.1	68.1	68.1	68.9	68.5	—
29	106.7	—	106.6	93.1	87.7	81.5	78.7	75.2	68.0	67.7	67.6	67.5	—	—
32	108.8	—	103.2	99.8	90.4	87.5	85.1	71.2	71.2	71.5	70.7	—	70.7	70.7
34	105.5	—	104.7	(84.8)	91.8	89.4	78.7	76.5	70.4	70.4	70.3	68.4	—	—
36	99.8	—	98.7	99.8	94.0	88.6	88.3	71.1	69.4	68.0	67.2	—	—	—
39	100.8	—	95.9	92.8	90.1	85.3	78.6	68.6	66.9	66.6	66.7	66.9	—	—
40	101.1	—	100.6	96.1	92.3	87.9	78.9	69.3	67.2	66.7	66.6	67.0	—	—
42	97.8	—	97.7	98.5	94.6	91.6	90.1	73.2	67.2	67.1	66.9	67.7	—	—
49	109.2	—	100.2	91.0	89.7	87.2	75.6	67.2	65.8	65.8	65.8	66.2	—	—
51	101.9	—	105.4	90.6	85.3	82.8	80.1	69.4	68.8	70.0	68.1	68.2	68.2	—
53	113.9	—	110.4	87.0	86.7	79.7	78.2	71.2	70.0	70.7	70.7	—	68.2	68.2
65	101.6	—	101.4	99.2	95.2	91.0	85.2	74.2	70.7	69.5	68.0	(950 m.)	—	—
66	101.1	—	101.8	96.7	89.0	85.4	79.7	70.8	69.6	67.8	66.3	(900 m.)	—	—
68	100.9	—	101.5	95.2	90.7	83.2	77.8	74.0	68.4	67.7	67.6	68.2	(1400m.)	—
69	105.1	—	106.9	86.2	86.7	85.3	79.8	70.5	66.9	66.3	67.7	66.9	—	—
70	103.0	—	106.9	91.4	80.1	82.3	78.2	71.6	68.4	67.7	67.6	67.6	(1450m.)	—

sides resemble each other in the water-layer above depths of 200 m., but a great difference is seen in the water-layer beneath 400 m., showing such values as 4 cc. and 50 % greater, respectively, than those of the Pacific side (Fig. 26).

(5) pH.

The determination of pH was carried out by the colorimetric method of Sörensen and Palitsch, using cresol-red as indicator, the results of which are given in Tab. 8. The horizontal difference of pH is generally small, and even at depths of from 50 m. to 200 m., the most variable zone, the differences between the two extreme values are of the order of 0.30–0.35. In the water-layer above 200 m. depth, the value of pH is less in the cold water-area than (i. e., comparatively more acidic) in the warm.

As to the vertical distribution, we have again the intermediate minimum layer for pH (relatively acidic intermediate layer) extending from 400 m. to 1500 m. depth, with its centre at a depth of from 800 m. to 1000 m., corresponding to the depth of the intermediate minimum layer for oxygen as previously described.

We have thus sufficient reasons for distinguishing three main water layers in the stratification of the Japan Sea, namely, the water layer at depths of from 0 m. to 200 m., 200 m., to 1000 m., and 1000 m. to the sea-bottom.

(6) Silicate (Tab. 9).

The horizontal distribution of silicate depends mainly upon supplies from below, so that it is naturally abundant in the upwelling areas.

The silicate content increases with increase of depth. The increase from 0 m. to 200 m. depth is very marked, while below 500 m., it is comparatively gradual, though uniform. At the surface, silicate is abundant in the Tusima Strait and in the coastal water-area along Japan Proper, which is probably due to the influence of land water. On the other hand, the surface layer of the North Tyôsen region is poor in silicate, but in the layer at depths of from 50 m. to 200 m., where the influence of the fresh water is not felt, the quantity of silicate is more abundant than at the same level in the warm water-area, which is probably due

Table 8. pH in the Japan Sea. ("Sôyô Maru", 1932.)

St. \ Depth (m.)	0	10	25	50	100	150	200	400	600	800	1000	1500	2000	3000
15	8.30	8.25	8.25	8.25	8.20	8.20	8.00	(185 m.)	—	—	—	—	—	—
16	8.30	8.25	8.25	8.25	8.20	8.20	7.90	*7.80*	*7.80*	*7.80*	(750 m.)	—	—	—
17	8.30	8.30	8.25	8.25	8.15	8.00	7.90	7.80	*7.75*	*7.75*	*7.75*	7.85	($1300_{m.}$)	—
20	8.30	8.25	8.25	8.25	8.25	8.20	8.10	7.85	7.80	*7.75*	*7.75*	—	—	—
21	8.30	8.25	8.25	8.25	8.10	8.05	7.90	7.85	7.80	*7.75*	7.80)	7.90	7.85	—
24	8.25	8.20	8.20	8.05	8.00	7.95	7.90	6.85	7.85	7.95	7.85	7.85	*7.80*	—
25	8.25	8.25	8.15	8.15	7.95	7.95	7.90	7.85	7.85	7.85	*7.80*	7.85	7.85	—
26	8.25	8.25	8.20	8.10	7.95	7.90	7.90	7.85	7.85	7.85	*7.80*	*7.80*	*7.80*	—
28	8.15	8.20	8.15	8.10	8.05	8.00	7.95	7.90	—	—	—	—	—	—
31	8.30	8.25	8.20	8.05	8.00	7.90	7.85	*7.75*	*7.75*	*7.75*	7.80	7.85	—	—
32	8.20	8.15	8.10	8.00	8.00	7.95	7.95	7.85	7.85	*7.80*	*7.80*	7.85	7.85	7.90
33	8.20	8.20	8.10	8.05	7.95	7.95	7.90	7.85	7.85	*7.80*	7.85	7.85	—	—
36	8.20	8.25	8.20	8.15	8.10	8.00	7.95	7.85	7.85	*7.80*	*7.80*	*7.80*	—	—
37	8.25	8.25	8.20	8.15	8.00	7.95	7.85	7.85	7.85	7.80	*7.75*	*7.75*	($1200_{m.}$)	—
40	8.25	8.25	8.25	8.20	8.20	8.10	7.95	7.75	7.75	7.75	*7.70*	7.75	—	—
42	8.25	8.25	8.25	8.25	8.25	8.20	8.10	7.85	7.80	*7.75*	*7.75*	*7.75*	—	—
44	8.25	8.25	8.25	8.25	8.25	8.20	8.10	7.85	*7.75*	*7.75*	—	—	—	—
47	8.30	8.25	8.25	8.25	8.25	8.25	8.20	8.20	(250 m.)	—	—	—	—	—
51	8.30	8.25	8.25	8.15	8.10	8.05	8.00	7.85	7.75	7.75	*7.70*	7.85	7.85	—
52	8.25	8.25	8.15	8.10	8.00	8.00	7.95	7.85	7.80	*7.75*	*7.75*	*7.75*	—	—
53	8.20	8.25	8.25	8.05	8.05	8.00	7.90	7.85	7.80	7.80	*7.75*	—	7.85	7.85
68	8.25	8.30	8.30	8.25	8.20	8.00	7.95	7.85	7.80	*7.75*	—	*7.75*	($1400_{m.}$)	—
69	8.30	8.30	8.30	8.10	8.05	8.05	7.90	7.85	7.80	*7.75*	*7.75*	*7.80*	—	—
76	8.30	8.30	8.30	8.25	8.25	8.20	8.10	—	—	—	—	—	—	—
mean	8.26	8.24	8.22	8.16	8.10	8.05	7.96	7.84	7.81	7.79	7.77	7.81	7.84	7.88
max.	8.30	8.30	8.30	8.30	8.25	8.25	8.20	7.90	7.85	7.95	7.85	7.90	7.85	7.90
min.	8.15	8.15	8.10*	8.00	7.95	7.80	7.85	7.75	7.75	7.75	7.70	7.75	7.80	7.85
amp.	0.15	0.15	0.20	0.30	0.30	0.35	0.35	0.15	0.10	0.20	0.15	0.15	0.05	0.05

Table 9. Silicate dissolved in the Japan Sea (mg./1 m^3). ("Sôyô Maru", 1932.)

amp.	0.15	0.15	0.20	0.30	0.30	0.35	0.35	0.15	0.10	0.20	0.15	0.15	0.05	0.05

Table 9. Silicate dissolved in the Japan Sea (mg./1 m³). ("Sôyô Maru", 1932.)

St. \ Depth (m.)	0	10	25	50	100	150	200	400	600	800	1000	1500	2000	3000
17	400	450	600	500	900	1500	1800	2700	3000	3600	3750	3750	(1300m.)	—
18	500	700	550	700	1200	1700	2500	2800	2800	3000	3700	3750	(1600m.)	—
19	530	550	650	700	750	1000	1200	2200	2600	2800	3200	3300	4000	—
21	700	600	580	850	1200	—	2000	2500	2800	3200	(2100)	(2800)	3750	—
23	750	800	750	650	1400	1900	2500	2500	3000	3000	3000	3700	3750	—
25	700	600	550	750	1700	1800	2500	2800	2800	3000	3000	3000	3850	—
26	450	700	650	1100	1500	1500	2000	2600	2700	3000	3100	3000	4000	—
30	450	—	500	1100	2200	2500	2400	2600	2700	2800	3750	4000	—	—
32	1500	—	2000	2000	2200	2500	2400	2800	2800	3300	3300	—	3750	3750
34	1100	—	730	1050	2000	2000	2400	2500	3000	3000	2800	3300	—	—
39	600	—	600	900	1600	1400	1800	2800	3000	3000	3000	3750	—	—
40	450	—	500	700	900	1300	1900	2800	3000	3000	3000	3750	—	—
42	450	—	500	600	800	1200	1300	2500	3000	3000	3000	3750	—	—
49	500	—	700	730	730	1400	1800	3000	3600	3800	3800	3800	—	—
51	760	—	700	730	1000	1600	1800	2700	3200	3800	3800	3600	3600	—
53	900	—	950	950	1500	1800	2000	2800	3200	3200	3600	—	4000	4000
68	500	—	500	500	850	900	1700	2200	2500	3000	3000	3100	(1400m.)	—
69	530	—	530	1000	1600	1300	1800	2200	2550	3000	3000	3000	—	—
70	500	—	500	880	1000	1200	1800	2250	2500	3200	3200	3200	(1450m.)	—
Mean	646	(629)	686	863	1317	1583	1979	2592	2882	3142	3216	3444	3838	3875

to active convection currents. In the warm water-area, the deep water below 500 m. is rich in silicate, exceeding 3000 mg/m^3, owing to a constant supply of it from the dead organisms that fall from the upper layer, and which are not taken up to such an extent by vertical convection as in the case of the cold water-area. Consequently, the vertical distribution of silicates is such that in the warm water-area the amount is small in the upper layer and large in the lower, while in the cold water-area the order is reversed.

(7) **Phosphate** (Tab. 10).

Horizontally, phosphate is abundant in areas of upwelling lower water. Its quantity is larger in the cold water-area than in the warm, and increases with increase of depth, showing an abrupt increase in the layer from 0 m. to 200 m. depth. As in the case of silicate, on the Tyôsen side, where vertical mixing is active, the vertical difference of phosphate is less than in the central part of the Japan Sea and on the side along Japan Proper.

In other words the upper water is subjected to the influence of the deeper water and acts more energetically in contrary manner upon the deeper layer on the Tyôsen side.

As a consequence of this, in the seas off the Tyôsen side, the nutrient salts are abundant in the upper water-layer and relatively scanty in the deep water-layer, especially in the water-layer corresponding to the upwelling area.

(8) **Nitrogen as Nitrate** (Tab. 11).

The general scheme of the distribution of nitrogen compounds resembles greatly that of the silicate and the phosphate above mentioned.

Summarizing the above, we may say that in the Japan Sea the nutrient salts for plankton life are scarce in the surface layer but increases with increase of depth. In the area of active vertical mixing, all the nutrient salts are abundant in the upper water layer and relatively poor in the corresponding deep water-layer. The horizontal distribution of the nutrient salts depends upon the intensity of vertical mixing, governed mainly by upwelling activity, as in the case of the Norwegian Sea and the North Sea.

Table 10. Phosphate (P_2O_5 mg./1 m^3.) dissolved in the Japan Sea. ("Sôyô Maru", 1932.)

St. \ Depth (m.)	0	10	25	50	100	150	200	400	600	800	1000	1500	2000	3000
17	10	10	10	25	40	100	120	120	165	160	160	170	(1300m.)	—
18	7	7	10	15	55	105	120	140	170	180	150	190	(1600m.)	—
19	10	5	15	15	15	25	55	130	160	170	155	170	220	—
21	10	15	15	15	30	—	110	110	150	160	130	160	205	—
23	18	15	35	50	110	110	110	140	165	170	155	165	210	—
25	10	35	35	45	70	90	110	130	155	175	220	160	205	—
26	15	15	45	55	60	80	110	120	165	175	180	180	220	—
30	17	—	20	55	70	105	120	145	145	175	200	200	—	—
32	20	—	50	55	70	100	110	145	145	175	180	—	220	160
34	10	—	35	55	35	70	105	140	145	180	170	210	—	—
39	10	—	25	45	45	35	115	150	150	190	210	210	—	—
40	10	—	25	45	40	40	90	150	150	150	220	240	—	—
42	5	—	15	30	30	40	50	135	140	280	210	200	—	—
49	5	—	30	60	100	100	170	260	380	280	310	300	—	—
51	5	—	25	60	70	120	180	200	260	290	310	300	310	—
53	10	—	30	65	110	120	300	270	280	280	290	290	290	—
68	3	—	10	45	115	120	150	190	225	280	280	300	(1400m.)	—
69	5	—	25	90	120	120	150	220	240	300	300	310	—	—
70	5	—	20	80	120	140	170	210	230	300	300	300	(1450m.)	—
Mean	10	14	25	48	69	90	129	163	191	204	217	225	235	

Table 11. N_2 as Nitrate (mg./1 m^3.) dissolved in the Japan Sea. ("Sôyô Maru", 1932.)

St. \ Depth (m.)	0	10	25	50	100	150	200	400	600	800	1000	1500	2000	3000
17	5	14	16	20	87	108	120	180	220	260	260	280	(1300m.)	—
18	6	13	16	34	96	108	120	195	215	245	245	260	(1600m.)	—
19	6	13	15	29	96	130	125	155	230	240	280	290	330	—
21	6	15	20	20	52	—	170	190	250	270	280	280	330	—
23	5	12	15	32	108	115	135	190	220	260	260	280	290	—
25	5	12	18	32	95	115	140	170	220	240	280	290	330	—
26	5	13	18	52	105	115	130	165	190	205	260	260	290	—
30	5	—	15	48	100	110	160	190	200	—	240	260	—	—
32	22	—	92	48	110	110	150	230	230	260	280	—	290	330
34	8	—	37	48	85	145	180	200	200	260	280	290	—	—
39	5	—	17	26	80	110	150	215	230	240	260	290	—	—
40	6	—	16	28	65	105	140	205	240	260	280	290	—	—
42	6	—	12	14	65	110	130	220	240	260	280	280	—	—
49	6	—	15	20	45	100	140	225	240	240	—	280	—	—
51	6	—	17	44	70	110	130	150	215	215	240	280	280	—
53	7	—	16	46	110	130	175	210	220	240	260	—	280	360
68	9	—	16	16	65	115	130	170	220	230	260	(1400m.)	—	—
69	9	—	17	56	—	80	150	160	220	245	280	—	—	—
70	11	—	18	20	105	145	145	170	215	230	245	(1450m.)	—	—
Mean	7	13	21	33	86	115	143	189	232	244	263	276	303	345

For the vertical distribution of nutrient salts (Fig. 27), we have the following empirical formulas;

$$P_2O_5 \fallingdotseq \frac{1}{10}\ (SiO_2-500)\ mg/m^3.$$
$$= 0.8\,Z \quad (Z<200\ m.)$$
$$= 31.6\,Z^{0.3} \quad (Z>300\ m.).$$

We find an essential difference in distribution between the layers above and below 200 m. depth.

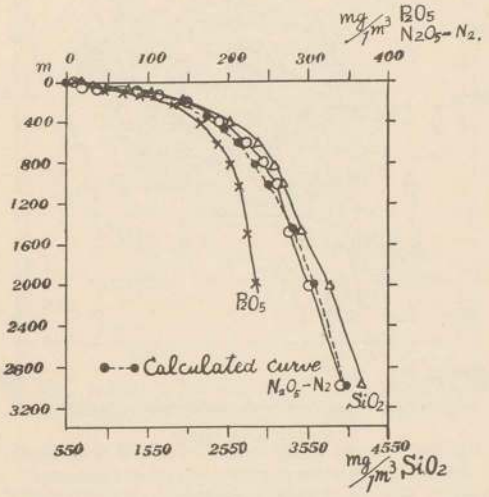


Fig. 27. Vertical Distribution of Nutrient Salts in the Japan Sea.

XIV. Dynamical Computation of the Currents.

(1) Distribution of Density *in Situ* and the Inferred Currents.

Firstly, the density *in situ* was computed for all stations, for levels of 0 m., 10 m., 25 m., 50 m., 100 m., 200 m., and 400 m. depths, and the general trends of isopycnals were plotted (Fig.

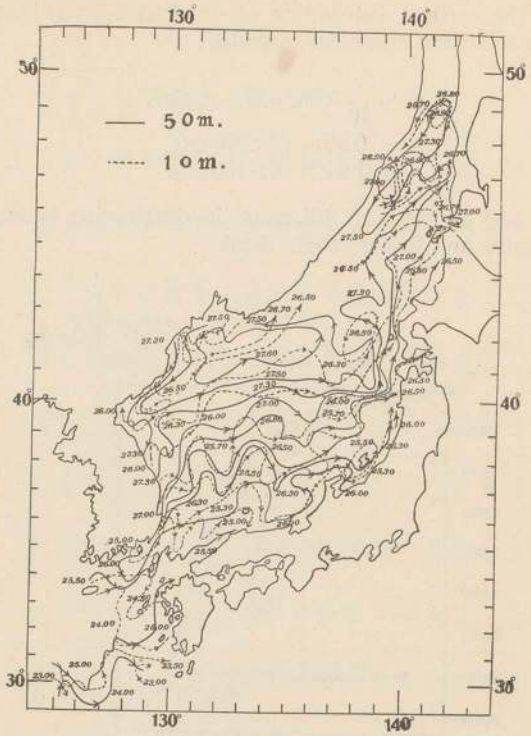


Fig. 28a. Density *in situ* (σ_t) at 10 m. and 50 m. Depth.
(Arrows indicate the directions of Currents computed).
(Early June, 1932.)

28). Since in the Japan Sea, the vortical currents are not very active, we have not taken the remark given by Prof. A. DEFANT[7] into consideration. We assumed, after Messres. K. SUDA[8] and R. SIGEMATU[9], that Bjerknes' solenoid theory can be applied to all parts of the explored area in the Japan Sea and accordingly investigated the general trends of the theoretical stream-lines.

A glance at Fig. 28 shows that the theoretical currents at all levels above 100 m. reproduce the typical features of actual currents in the upper and intermediate layers in the Japan Sea.

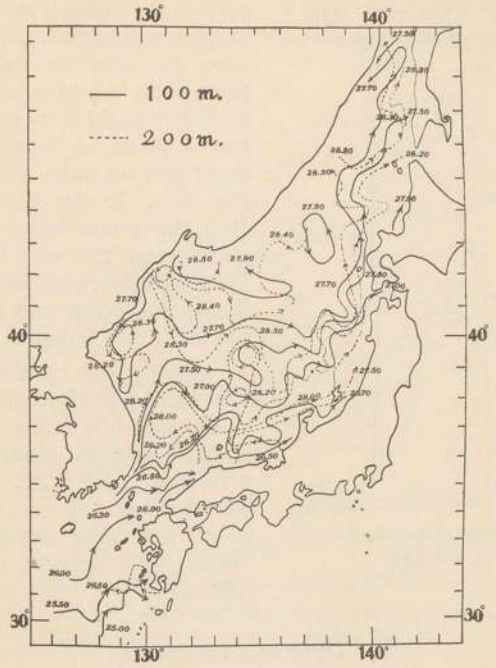


Fig. 28b. Density *in situ* (σ_{t}) at 100 m. and 200 m. Depth.
(Arrows indicate directions of Currents computed.)
(Early June. 1932.)

The water-masses of higher density in the seas off North Tyôsen and west of Karahuto indicate the existence of a cyclonic vortical current.

Upon descending from the surface to the lower layer, the extent of the warm current-area diminishes, while the cold current-area, on the contrary, increases. As already recognized in the distribution of dissolved oxygen, the cold current-system along the eastern sea of Tyôsen sends out a branch-current towards the western entrance of the Tugaru Strait and becomes gradually conspicuous with increase of depth from the surface layer (0 m.–10 m.) to depths of 25 m., 50 m. and 100 m. In the layer at 200 m. depth, conditions suddenly change. The stream-lines of the cold

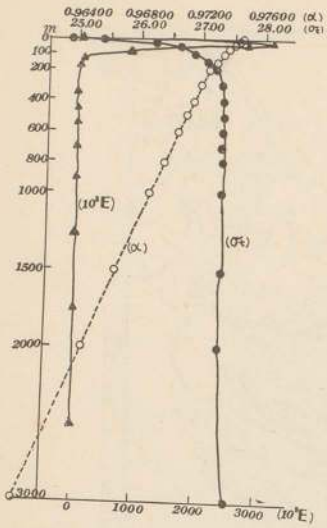


Fig. 29. Vertical Distribution of σ_t, α, and 10^8 E.

current, diverging from the North Tyôsen sea-region to the south, cover the northern half of the Japan Sea, whereas the north-going stream-lines are confined to that area along Japan Proper, about fifty sea-miles distant from the coast. In the layer 400 m. deep, the stream-lines of the cold current that diverge from North Tyôsen are developed more extensively, and the currents generally get feeble and irregular.

σ_t increases suddenly with increase of depth from the surface to 200 m., while below 300 m., it is approximately constant, with a value of about 27.37. σ_{tD} also increases suddenly to a depth of 200 m. and then increases uniformly with increase of depth (Fig. 29).

(2) Dynamic Meter (D).

After computing the value of the dynamic meter from the water temperature and salinity by means of data obtained by the "Sôyô Maru", we plotted a dynamic topographical chart (Fig. 30), taking a level of 400 decibars for standard. Since Fig. 30 is based on the data of only one boat, the "Sôyô Maru", and since the currents are plotted on the assumption that they were stationary during the period from the middle of May to the middle of June, some differences will be noticed between Fig. 30 and Fig. 28, the latter being based on data obtained by a number of boats and carried out in the same interval of days. The general trends however agree well with each other.

(3) Specific Volume (α).

From the isostere in the figures of sections obtained by the "Sôyô Maru", we inferred the presence of vortical currents and

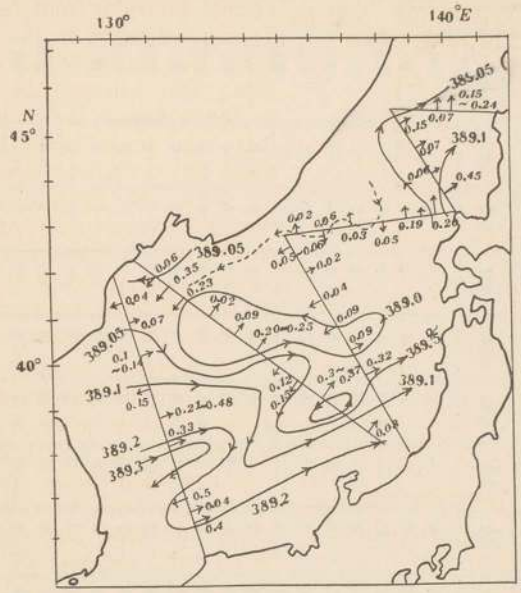


Fig. 30. Surface Current inferred from Dynamic Topographical Chart. (Standard Surface, 400 Decibar Surface.) "Sôyô Maru", 1932.

located two branches of the warm current with the vortical current flowing between them.

(4) Computed Current Velocity (V cm/sec).

The velocities were computed in accordance with the Bjerknes-Sandström's Theory at every station of the cross sections investigated by the "Sôyô Maru" (Tab. 12). The vertical distribution of the computed velocity is shown in Fig. 31. The velocities are fairly uniform in the upper layer above 50 m. depth, while a comparatively high velocity of 0.2–0.5 knot is encountered in the zone corresponding to the branch-water of the Tusima Warm Current-System, as previously mentioned, thus corroborating the existence of a warm branch-current in the middle of the Japan Sea.

In other regions, except the area of the main and branch

Table 12. Current Velocity (cm/sec.) computed from Bjerknes' Theory.

Depth (m.) / St.	0	10	25	50	100	150	200	300	400	500	600	800	1000	surface Layer above the 50 m. Depth
														kn.
At the Middle of St. 16–17	22	21	20	19	13	7	2	—	2	—	0	—	—	0.4
17–18	0	0	0	− 2	4	8	8	—	6	—	3	—	0	0
18–19	−26	−26	−26	−25	−22	−17	−13	—	− 5	—	− 2	−1	—	0.5
19–20	− 2	− 2	6	6	6	6	7	—	5	—	2	1	0	0
20–21	14	15	15	14	12	9	4	—	− 2	—	− 1	—	0	0.3
21–22	22	21	12	11	12	6	6	—	4	—	1	0	0	0.4
22–23	− 6	− 7	− 8	− 7	− 9	− 6	− 6	—	− 4	—	− 1	−1	0	0.15
23–24	6	7	6	4	1	1	1	—	1	—	0	0	0	0.15
24–25	4	3	3	3	3	2	2	2	2	2	2	1	0	0.1
25–26	− 2	− 2	− 2	− 2	− 2	− 2	− 2	− 1	− 1	0	0	1	0	0.05
29–30	− 4	− 3	− 3	− 3	− 2	− 1	− 1	− 1	− 1	− 1	− 1	−1	0	0.1
30–31	−16	−17	−17	−17	−18	−18	−18	−18	−16	−13	−10	−4	0	0.35
31–32	−12	−12	−11	−11	− 9	− 8	− 7	− 5	− 3	− 3	− 2	0	0	0.25
32–33	1	1	1	1	1	0	0	0	1	1	0	1	0	0
33–34	5	5	4	4	4	4	4	5	5	4	4	1	0	0.1
34–35	13	12	12	10	8	7	5	3	2	1	0	−1	—	0.25
35–36	− 6	− 6	− 6	− 6	− 7	− 6	− 6	− 5	− 4	− 3	− 2	0	—	0.1
36–37	− 7	− 8	− 7	− 7	− 4	− 3	− 3	− 1	− 1	0	0	0	0	0.15
37–38	19	18	15	10	7	5	3	2	0	—	—	—	—	0.35
38–39	− 2	− 2	− 1	− 1	− 1	− 2	− 1	− 3	− 2	0	—	—	—	0.05
39–40	− 2	− 2	− 3	− 2	− 2	− 2	− 2	− 2	− 2	0	− 1	1	0	0.05

38–39	− 2	− 2	− 1	− 1	− 1	− 2	− 1	− 3	− 2	0	—	—	—	0.35
														0.05

39–40	3	3	3	2	2	2	2	2	2	0	− 1	1	0	0.05
50–51	17	16	16	15	14	13	13	11	9	8	7	3	0	0.3
51–52	5	5	4	4	3	1	0	− 1	0	− 1	0	− 1	0	0.1
52–53	− 4	− 5	− 5	− 5	− 5	− 5	− 4	− 5	− 3	− 3	− 2	−2	0	0.1
53–54	− 2	− 2	− 3	− 3	− 4	− 5	− 3	− 2	− 1	0	—	—	—	0.05
54–55	1	1	1	1	2	3	1	1	0	0	—	—	—	0
55–56	− 3	− 3	− 3	− 3	− 2	− 2	− 2	− 1	− 1	0	—	—	—	0.05
56–57	− 2	− 1	− 1	− 1	0	0	0	0	0	0	—	—	—	0
57–58	− 3	− 3	− 3	− 3	− 3	− 3	− 2	− 1	0	0	—	—	—	0.05
58–59	2	2	2	1	1	1	1	0	− 1	0	—	—	—	0.05
59–60	− 3	− 3	− 2	− 2	− 3	− 2	− 3	− 2	− 1	0	—	—	—	0.05
60–61	9	9	9	9	9	9	7	6	2	0	—	—	—	0.2
61–62	1	1	0	1	0	− 1	− 1	0	1	0	—	—	—	0
62–63	11	10	10	6	− 1	− 5	− 5	− 2	− 1	0	—	—	—	0.2
65–66	23	23	22	21	15	8	4	2	3	2	2	1	0	0.45
66–67	3	3	3	1	0	− 1	− 1	− 1	0	0	0	—	—	0.05
67–68	3	3	3	3	3	3	3	2	1	0	0	—	—	0.05
68–69	7	7	6	5	2	0	− 1	− 2	− 1	− 1	0	0	0	0.1
69–70	− 1	− 1	− 1	0	− 1	− 2	− 2	− 1	− 1	0	0	0	0	0
70–71	4	3	3	3	2	2	1	0	0	—	—	—	—	0.1
71–72	12	12	10	8	4	2	1	1	0	—	—	—	—	0.2
$\lvert\bar{v}\rvert$ Mean	7.5	7.4	7.0	6.5	5.5	4.6	4.0	3.0	2.4	1.4	1.6	1.0	0	
	Approximately Equal Vel.					Suddenly Decrease				Approximately at Rest				

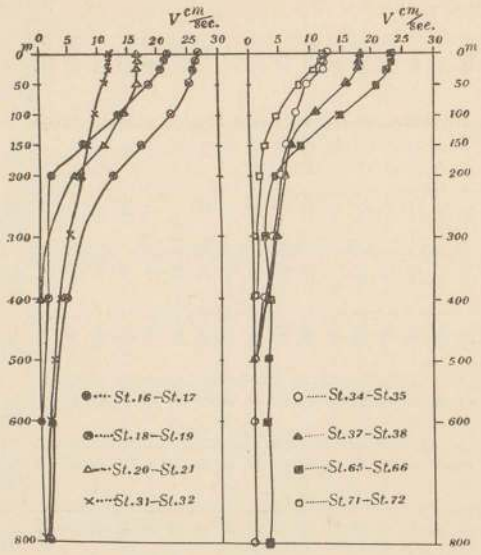


Fig. 31. Vertical Distribution of Velocity Computed from Bjerknes' Theory.

warm current, the velocities are generally small and of the order of 0–0.2 knot, which is less than the value inferred from the current-bottle experiment, and which is probably because the influence of wind-drift is sensible to a certain degree on the surface layer of the Japan Sea.

The currents flow with full strength and volume in the layer down to 200 m. depth. Beneath this, the velocity suddenly falls, and beneath at least 400 m. and 500 m., the currents are so feeble as to be scarcely recognizable.

XV. Direct Measurements of Currents.

(1) Measurements of Currents with Drift-Bottles.

For investigating the general trends of currents, we threw overboard nearly 6800 current-bottles, fitted with a small drag made of tin-plate, and hanging down from the end of a wire 1 m.

long, into the explored water-area as shown in Fig. 1. The results were quite successful, the percentage of bottle recovery being 25 % over the whole area and 34 % for the Japan Sea.

(i) Spatial Density of Recovered Drift-Bottles (Fig. 32).

The regions where the bottles were picked up abundantly are those where the stream-lines are crowded most densely, in the

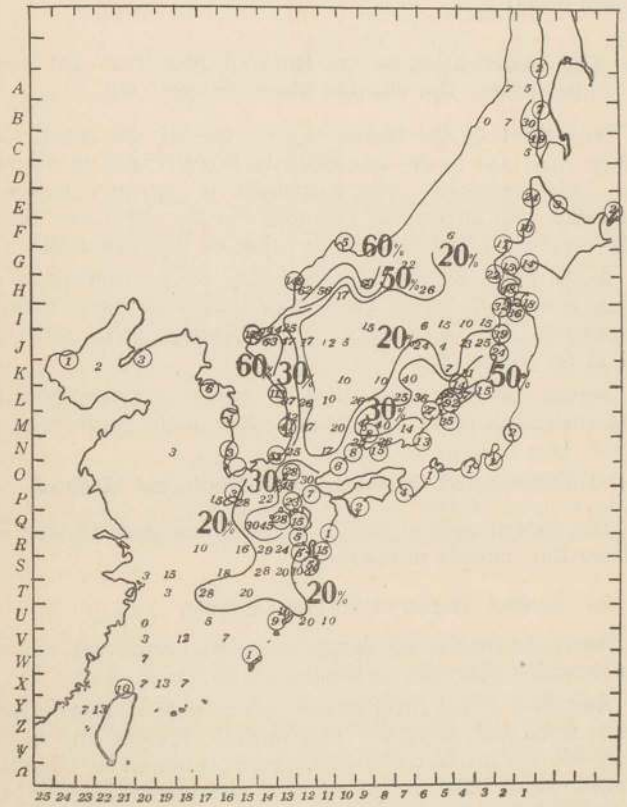


Fig. 32. Spatial Density of Recovered Drift-Bottles and Rate of Recovery for each Point of Bottles thrown (%). (figures in the circle denote the indice of density)

Tusima Strait and the Tugaru Strait, for example, or in regions where the currents upon striking the coast sink down in front of it, thus forming a convergence of stream-lines (for example, the west coast of Noto-Peninsula, the vicinity of Oga-Peninsula, the east coast of Tyôsen, etc.), or in regions where the bottles have accumulated, being captured by topographic vortical currents (for example, Toyama Bay, the coastal waters of east Tyôsen), or in regions of complicated coast-line, as in the vicinity of Tugaru Strait.

(ii) The Distribution of the Rate of Recovery for each Point where the Bottles were thrown (Fig. 32).

Over 60 % of the bottles thrown out off the North East Tyôsen coast and in the area extending from Niigata to Toyama have been recovered. The percentage of recovery generally diminishes with increase of distance from the coast, and seems to be inversely proportional to the distance from the land.

In the Japan Sea, as in a great lake, the percentage of recovery is naturally higher (34 %) than that in other seas, it being for example 15 % in the seas south of Tusima Strait and only 7 % in the Yellow Sea.

Hence, current measurement by means of current-bottles fitted with small drags is of special value in the Japan Sea.

(iii) Inferrence of Currents by Drift-Bottle Method.

The method adopted here is the same as that adopted for Wakasa Bay, already mentioned.[10]

(a) General Trends of Surface Currents.

Along the coast of the Japan Sea a counter-clockwise circulation is readily observed, as pointed out by Dr. Y. WADA.[11]

According to our investigations, which embrace also currents remote from land, there are two vortical currents, one in the warm and one in the cold current-system, while on the boundary between them, there are divergences and convergences of the currents, besides mingling of vortices. In other words, most of the bottles that were thrown into the cold current-system were picked up on the north and east coasts of Tyôsen and on the south

Siberian coast, while those thrown into the warm current flowing north were recovered on the coasts of Japan Proper, Hokkaidô, and Karahuto. The bottles thrown into the boundary between the cold and warm water-areas were found here and there in the cold and warm water-areas, respectively. The stations from which the divergence of stream-lines seems to take place, lie on an elongated zone corresponding to the boundary of the two water-masses. The current velocity is about 0.2–0.5 knot in the cold water-area and about 0.3–0.5 knot in the warm water-area along the coast of Japan Proper (in the Tugaru Strait and Tusima Strait, particulary, the velocities are usually over 1 knot). As to the bottles picked up on the North Coast of Hokkaidô, the velocity is estimated to be about 0.2–0.3 knot.

The mean velocity in the Kurosiwo-area is 0.5 knot, and in the Yellow Sea less than 0.2 knot.

(b) Counter-Current-Area in the Tusima Warm Current.

In the middle of the warm water-area, the existence is inferred of an unusual region, whence an extraordinary rate of recovery of bottles on the coast of Japan Proper has been recorded, probably on account of counter-currents entering the surrounding waters. Indeed, the region in question fits in well with the counter-current-area previously supposed from the sectional distribution of water temperature, salinity, dissolved oxygen, the degree of oxygen saturation and specific volume. The possible reasons for such a west-going counter-current with small velocity will be given later. It is easily understandable however that the intensity of a counter-current shows its highest point or decline according to variations in the intensity of flow of the Tusima branch Current.

(c) Division of the Flux.

All the bottles that were thrown into the warm current-area in the southern part of the Japan Sea, after drifting about, were found concentrated in the west entrance of the Tugaru Strait. The greater part of them were picked up on the coast of Tugaru Strait after having passed through the Strait into the Pacific side of Japan Proper. The remainder, after continuing their northerly journey, divided again at the Sôya Strait into two branches, one entering the Sôya-Current flowing along the north coast of Hokkaidô, and the other drifting along the west coast of Karahuto.

Such branching off in the drift of bottles corresponds to the division in the amount of flux.

By a simple computation* it can be shown that about 60–80 % of the water-mass flowing into the Japan Sea through the Tusima Strait flows out from the Tugaru Strait, while the remaining quantity, which corresponds to about 20–40 % of the original water-mass, continues its northerly journey.

Since we cannot ignore the effect of the quantity of land-water that flows into the Japan Sea, plus the increase by precipitation and minus the decrease by evaporation, the actual efflux may greatly exceed the quantity above computed. It is plausible to suppose that more than half of the water remaining is captured by the Okhotsk Sea side, because the strong current in the Sôya Strait is comparable in intensity to the Tugaru Strait current.

As regards the branching off of the Tusima Current from the Kurosiwo, bottles thrown south of 30° N were cast ashore on the west coast of Kyûsyû and on the Pacific side of Japan proper, while a few were found that had passed through the Tusima Strait. No bottles thrown south of 33° N were picked up north of Keisyô Hokudô, on the Tyôsen side: most of them were found on the side of Japan Proper. None thrown north of 33° N were recovered on the south coast of the Pacific side of Japan Island, while some that were thrown out south of 33° N were cast ashore there. In the Yellow Sea, there seems to be a cyclonic vortical current in its northern part, as judged from the results of drift-bottles experiments. The extention of fresh water there in summer was inferred from the course taken by bottles thrown in the sea east off Central China, most of which flowed into Tusima Strait.

(d) Intersection of Stream-Lines.

Some singularities are observed, such as the apparent intersec-

* The cross-sectional areas of the four entrances into the Japan Sea are as follows: Tusima Strait 11.45 km², Tugaru Strait 22.1 km², Sôya Strait 1.841 km². Mamiya Strait 1.062 km².[4]

The velocities obtained by current measurements made with current-drags, to be mentioned later, are respectively: Tusima Strait about 0.5 knot, Tugaru Strait about 2 knot, as used in the following equation:

$$X\ (0.5\,\text{kn.} \times 11.45) = 2\,\text{kn.} \times 22.1 \quad \therefore \quad X = 80\ \%.$$

By assuming the velocity in the Tugaru Strait to be 1.5 kn., X=60 %.

tion of divergences and convergences of stream-lines, and fluctuations in the course of time in the lines of flow.

The majority of drift-bottles find themselves either in the cold or in the warm current-systems, although off the southern part of Keisyô Hokudô of the Japan Sea a few of them pass from the cold current-system into the warm, while in the northern part of the Japan Sea a few more of them shift from the warm current-system into the cold. The general mode of these shifts is in cyclonic sense.

(e) Some Peculiarities of Drift Course.

(i) A bottle liberated at station (21°20′ N, 128°08′ E) on June 7, 1932, was picked up on Feb. 17, 1933, 255 days later, on the coast of Kelantan, Bachok, Malay States, about 1500 sea-miles distant. This indicates that a current flows south from the Strait of Formosa, along the coast of Asia, with a mean velocity of at least 6 sea-miles a day.

(ii) A bottle thrown out near C. Nisinotoro on June 10 was fonnd near Hunka Bay 122 days later; it had probably drifted away from the Sôya Warm Current-Area to the Oyasiwo water-area along the south coast of Hokkaidô.

(2) Current Measurements by Means of Current-Drags.

During early June a number of current-drags[10] were liberated simultaneously from 32 stations off the coast of the Japan Sea, their courses followed, and their hourly positions determined (Fig. 33).

These observations gave us the desired information in regard to the so-called Tusima Current for that period.

Notably strong currents flow in the seas near the south end of Karahuto: these have a velocity of about 1–2 knots. In the Tugaru Strait they have a high velocity of about 2 knots, while at the station off Henasizaki, at the west entrance of Tugaru Strait, they flow north with a velocity of 1–2 knots. In the adjacent seas from Akita to Niigata Prefecture, a north-going current having velocity of 0.5 knot was found. In Wakasa Bay and in the sea off the west coast of Noto-Peninsula, the velocity was 0.5–1.5 knots in a NE direction, while in the seas from Simane

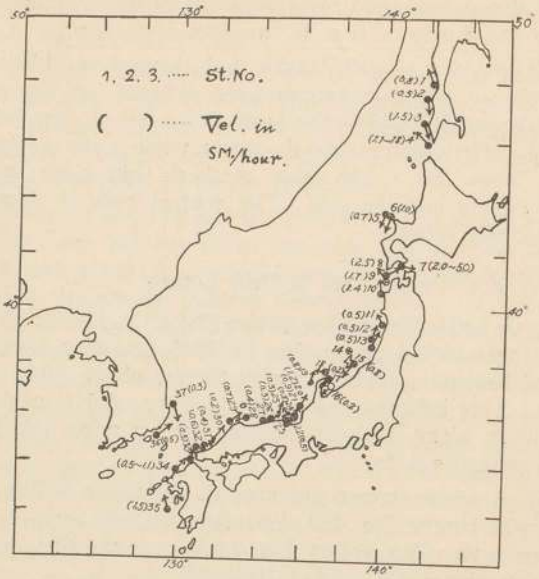


Fig. 33a. General Sketch of Currents Measured by Current-Drags Liberated.

St.		Date
1.	Kusyunnai	V. 31.
2.	Konotoro	VI. 28.
3.	C. Kenusi	VI. 13.
4.	Nisinotoro	VI. 12.
5.	C. Kamoi	VI. 10.
6.	C. Kamoi (Current Meter)	VI. 10.
7.	Ômazaki	VI. 2.
8.	Sirakamizaki	V. 29.
9.	Gongenzaki	VI. 17.
10.	Henasizaki	VI. 14.
11.	Hirasawa	VI. 5.
12.	Tobisima	VI. 11.
13.	Kamo	VI. 10.
14.	Hadumizaki	VI. 3–4.
15.	Strait betw. Sado & Niigata	VI. 8.
16.	Namerigawa	VI. 4.
17.	Usetu	VI. 2.
18.	Rokugôzaki	V. 30–31.
19.	C. Saruyama	VI. 6.
20.	Andôzaki	VI. 15.
21.	Etizenzaki	VI. 14.
22.	Kutusima	VI. 21.
23.	Araizaki	VI. 24.
24.	„ „	VI. 22.
25.	Kyôgazaki	VI. 20.
26.	Nekozaki	VI. 18.
27.	Amarube	VI. 19.
28.	C. Dizô	VI. 10.
29.	Hinomisaki	VI. 12.
30.	Hamada	VI. 8.
31.	Ôsima	VI. 10.
32.	Kawazirimisaki	VI. 9.
33.	Hutamizima	VI. 8.
34.	Genkaizima	VI. 9.
35.	Onukizaki	VI. 10.
36.	Huzan	VI. 9.
37.	Seika	VI. 2.

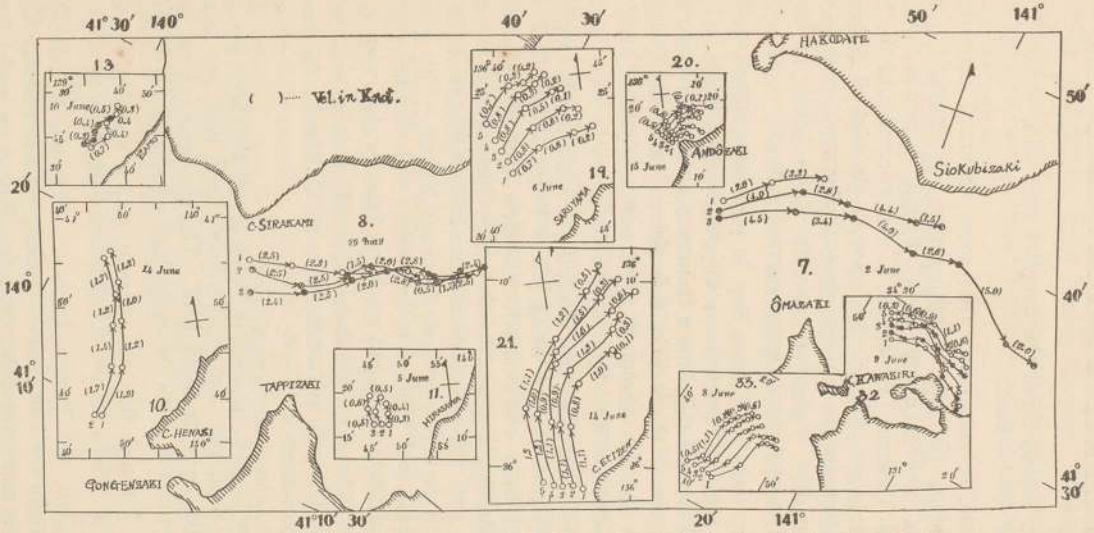


Fig. 33b. Examples of Currents Measured by Current Drags in the Sea-Districts 7, 8, 10, 11, 13, 19, 20, 21, 32, 33 indicated in Fig. 33a.

to Yamaguti Prefecture it was about 0.5 knot (0.2–1.0 knot) in a NE direction.

In the Tusima Strait the currents were fairly strong with a velocity of 0.5–1.0 knot.

It should be stated here that some abnormal currents are observed along the coast of Japan Proper; for example, a feeble south-going counter-current off C. Kamoi, a nearly immobile current off Tobisima (Yamagata), a counter-current in the Strait between Sado and Niigata. Moreover, in the seas off Hyôgo and Kyôto Prefectures, the currents are generally weak, some of them being even slow west-going currents. Off C. Dizô, in Simane Prefecture, a west-going counter-current is found.

The currents in Wakasa Bay, in particular, differed remarkably from what we found from our observations made in July, 1930.[10] We found this time a counter-clockwise vortical current with its center at the north of Kaburizima, east of C. Kyôgazaki, besides an easterly current off Ohama Bay activated by a secondary vortical current in Wakasa Bay.[10]

All these anomalies may probably be explained by supposing that the Tusima Current along Japan Proper, which had been progressing in a north-easterly direction from C. Hinomisaki, took at that time a course much farther offshore than in normal years and thus induced a counter-current in the seas off Hyôgo, as well as in the region between Akita and Niigata. This anomaly may be noted with interest in connection with the unfavourable condition of the sardine and mackerel fisheries that year.

Near C. Konotoro (Karahuto), the end of the warm current is found to approach the coast, while off C. Kenusi, its counter-current flows south.

West and east of Tugaru Strait the stream-lines are comparatively dispersed, but in the Strait itself they are densely crowded, the currents being ENE. The strongest current in the central part of the Strait shows the high velocity of 2.5–5.0 knots.

Inside Toyama Bay are currents with a velocity above 0.5 knot, and off Usetu with a velocity of 0.4–0.5 knot.

Off Huzan, the Tusima Current, which has a north-going direction along the east coast of Tyôsen, has a velocity of 0.4–1.2 knots. This current probably branches off from the main Tusima

Current, forming a continuation of the East Tyôsen Warm-Current, branching off from the main Tusima Current.

Off the east of Geizitu Bay, the stream-lines belonging to the warm and cold currents mix together, resulting in a small cyclonic vortical current.

(3) Current Measurements with the Ekman-Merz Current-Meter.

Observations with this instruments were carried out at 8 stations during 25 days around June 5, by the vessels "Sôyô Maru", "Tankai Maru" "Hatutaka Maru", "Hisyun Maru", "Syôhô Maru", and a boat belonging to the Taihoku Fisheries Experimental Station.

The hourly continuous observations during these 25 hours were carried out at 3 stations in the Yellow Sea, 2 stations in the Japan Sea, and 1 station in the Strait of Formosa.

The Yellow Sea, the Pwok Hai, and the east China Sea generally have strong tidal currents. In these seas the currents in the lower water-layers are only a trifle slower than the currents in the upper water-layer, although the residual currents are very feeble.

As the influence of tidal currents in the Japan Sea is considerable, it is hoped that a continuous observation during at least 25 hours may be made in future studies of this Sea.

(i) NE 20 SM. off Taiankô in the Strait of Formosa.

In the layer of 5 m. depth the average current has a velocity of 1–4 knot in a N 31° E direction, the time of the strongest current being 17–18 h. The residual currents are more conspicuous than the tidal currents. At 20 m. depth the residual current is about 0.9 knot, in a N 38° E direction, with a predominat tidal current of semi-diurnal period. At a depth of 60 m., the current is about 0.8 knot in a N 42° E direction. The current velocity decreases with increase of depth, and the direction of the current is deflected in clockwise direction.

(ii) SE 20 SM. off Saisyû Tô in the East China Sea (Fig. 34a).

Compared with the feeble residual current with velocity less than 0.2 knot in N-E direction, the tidal current is very strong

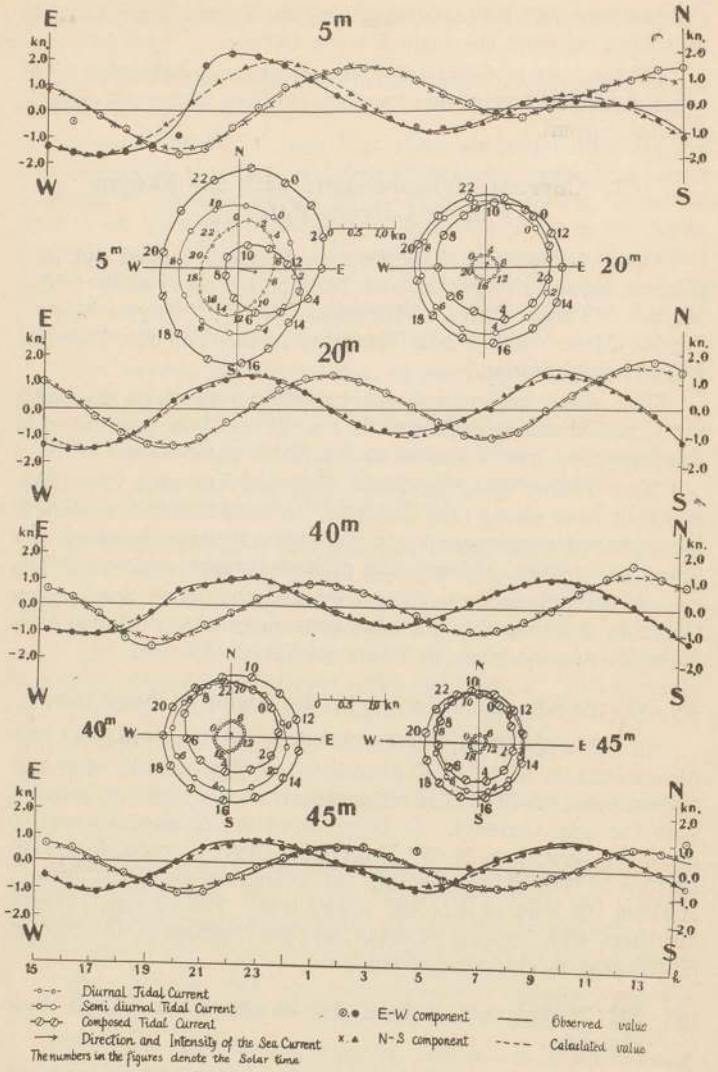


Fig. 34a. Current Measurement by Current-Meter.
("Hatutaka-Maru", June 4–5, 1932. at 31°44′30″ N, 124°50′30″ E.)

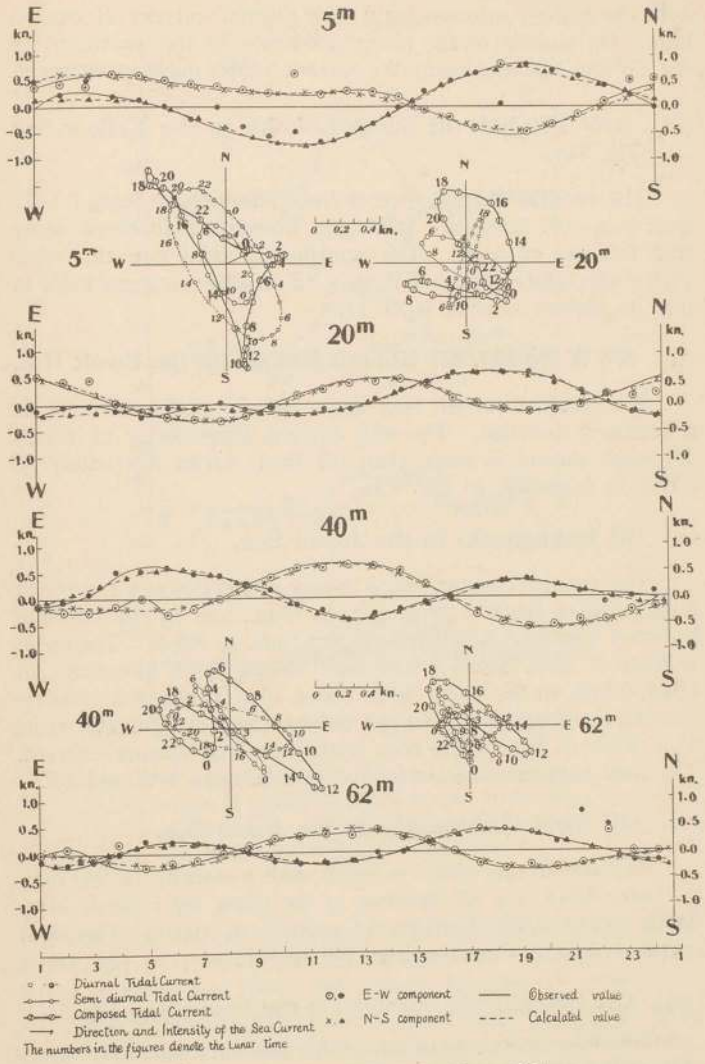


Fig. 34b. Current Measurement by Current-Meter.
("Hisyun Maru", June 5–6, 1932. at 36°02′ N, 122°32′ E.)

with the highest velocity for a semi-diurnal current of over 1 knot. On account of the phase difference in the variations of the EW-and NS-components, the current rotates in clockwise sense.

(iii) S/W 110 SM. off Santô Kôkaku in the Yellow Sea (Fig. 34b).

The residual current here is feeble, its velocity being 0.1–0.3 knot in a N-E direction. It rotates in counter-clockwise sense with increase of depth. The semi-diurnal tidal current, which varies alternately from a NW to a SE-direction, is remarkable in that its highest velocity is 0.8 knot.

(iv) SWW 30 SM. off Kimotô Kôkaku in the Pwok Hai.

The residual current here has a velocity of 0.1–0.2 knot in a northerly direction. The tidal current, the velocity of whose strongest current is more than 0.5 knot, varies alternately in direction from NW to SE.

(v) Off Rokugôzaki in the Japan Sea.

The residual current, which is very feeble, flows in a westerly direction at a depth of from 0 m. to 10 m., and in the opposite direction (easterly) at a depth of from 50 m. to 100 m. The mean velocity at 50 m. depth is 0.16 knot in a S 43° E direction. In other words, in the upper layer above 10 m. depth is a counter-current, as observed in the strait between Sado and Niigata, while at a depth of 50 m. there is an intrusion of the Tusima Current. The tidal current oscillates in direction between NW and SE.

(vi) Off Sado Hadumizaki in the Japan Sea.

The sea-current, which is feeble with a velocity of less than 0.1 knot, flows in a SE direction in the upper layer above 50 m. depth and in a NE direction at a depth of 100 m. The tidal current varies in direction from NE to SW.

(vii) Off Gongenzaki (Aomori) in the Japan Sea (Fig. 34c).

The direction of sea-current, which flows in a northerly direction with a velocity of about 0.2 knot, gently oscillates between NE and NW, with increase of depth.

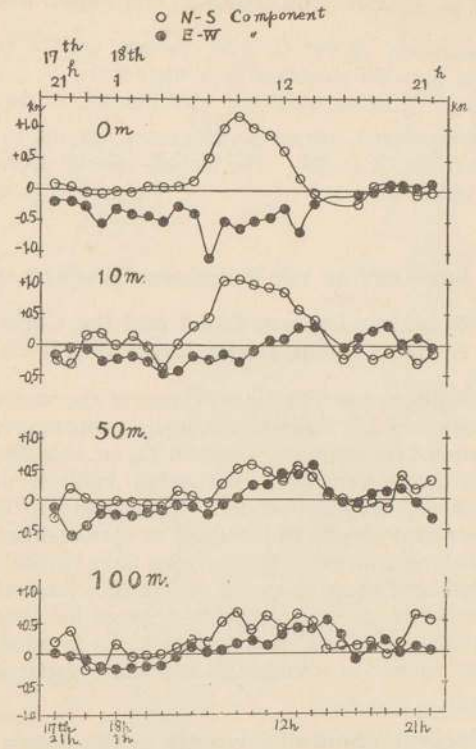


Fig. 34c. Currents measured by Ekman-Merz Current Meter at C. Gongen in Aomori Prefecture on June 17–18, 1932. (Sôyô Maru). (currents at the surface were measured by means of a small drag.)

The tidal current is strongest in the upper layer, above 10 m. depth, and its north component amounts to 1 knot, though, at depths of 50 m. and 100 m. the velocity is about 0.5 knot.

The semi-diurnal tidal current becomes apparent with increase of depth, although the diurnal current predominates on the whole. The phase of the strongest north current lags gradually with depth increase.

(viii) Off C. Kamoi (Hokkaidô) in the Japan Sea.

The unusually strong residual current, with a velocity of 0.5–1.0 knot in a SW direction, as already found by current-drag experiment, is deflected westward with increase of depth.

The diurnal tidal current predominates, varying in direction alternately from NE to SW. The current-velocity decreases with depth increase.

XVI. Summary of the Foregoing Investigations.

(1) Synthetic Current Chart and the Current-Systems in the Upper Layer (Fig. 35).

In its features, the distribution charts of the various hydrographical elements (air temperature, water temperature, salinity, water colour and transparency, dissolved O_2, etc.) closely resemble the current-charts that were constructed indirectly from the isopycnals *in situ*, the dynamic-meters, etc., and also with the current-charts constructed directly with the aid of current-drags, current-bottles, and current-meters. Summarizing these results, we constructed a synthetic chart as shown in Fig. 35. Since this figure shows at a glance the hydrographical features for a certain time interval around early June, it should be borne in mind that the currents are subject to considerable seasonable variation.[14]

(2) General Trend of Currents in the Japan Sea.

Masses of warm and salty water, which come into the Japan Sea through the Tusima Strait, flow out with a high velocity through the two straits of Sôya and Tugaru. A cold and comparatively fresh water, belonging to the so-called Liman Current-System, flows in through Tartary (Mamiya) Strait, but in our opinion the quantity is very small, contrary to the inferences of Schrenck,[13] Makaroff,[10] etc.

In the seas adjacent to the southern Siberian Coast and North Tyôsen, exists a source of relatively fresh and cold water, although the two large warm and cold water-masses keep up the two large vortical circulations, which are almost independent of each other, and mingle only on their boundary zones.

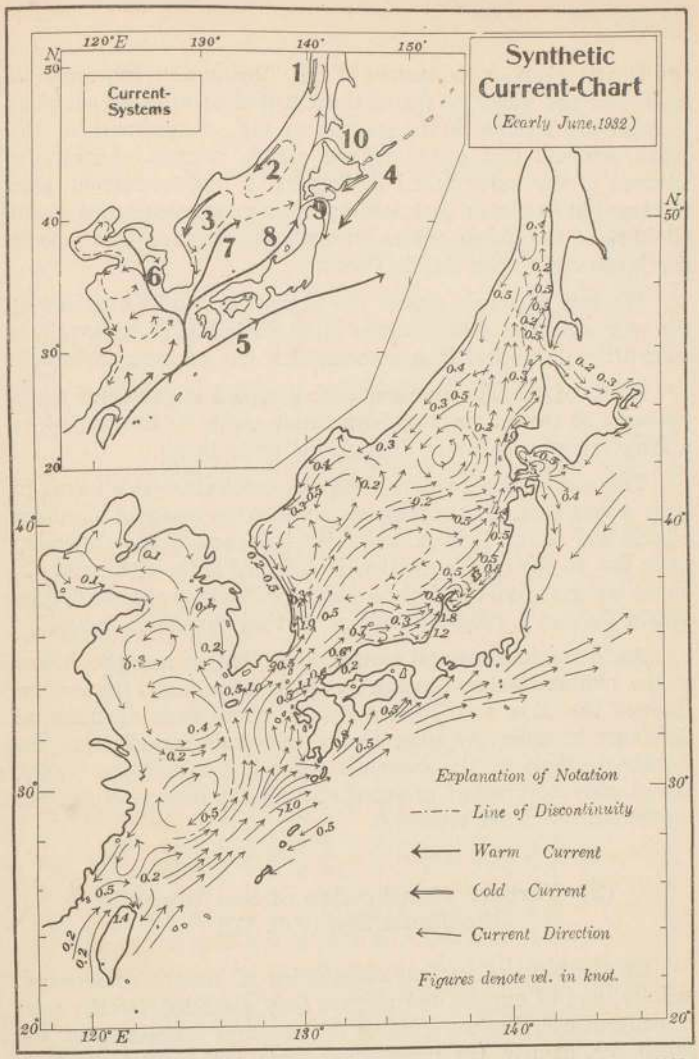


Fig. 35. Currents in the Japan Sea and its Adjacent Waters in Early June, 1932.

1. Liman Cold Current
2. Cold Current along Siberian Coast.
3. North Tyôsen Cold Current.
4. Oyasiwo Cold Current.
5. Kurosiwo Warm Current.
6. Warm Current in the Yellow Sea.
7. East Tyôsen Warm Current.
8. Tusima Warm Current.
9. Tugaru Warm Current.
10. Sôya Warm Current.

Observations of the course of the Tusima Current make it seem that the water of Warm Current-System, after its entrance through the Tusima Strait, spreads to the greater part of the Japan Sea and that owing to the earth's rotation, during the advance of the water in a NE direction a counter-current area is formed in its central part, when a water-mass constituting about 60–80 % of the inflow passes through the Tugaru Strait from the Japan Sea to the Pacific Ocean.

We may therefore expect the stream-lines to be crowded at the west entrance of the Tugaru Strait, as in Fig. 35, although no exhaustive theoretical interpretation of it has yet been attempted.

North of the Tugaru Strait, the diverged stream-lines again converge at the entrance of Sôya Strait, owing to the outflow of a large quantity of water through the latter Strait.

The south-going current along the continental side forms in such a way that, (1) the water adjacent to the coasts of southern Siberia and North Tyôsen, under the influence of the deflecting force due to the earth's rotation, is deflected to the right, and, (2) due to topographical restrictions, under the influence of East Tyôsen Warm Current a counter-clockwise vortical current is induced.

As to the fundamental motive force that causes the inflow of the southern waters through the Tusima Strait and the outflow through the Sôya and Tugaru Straits, some such agencies as difference in water pressure, tidal or meteorological-effect, or the combined effects of the current-systems in the northern Pacific Ocean, may be invoked to explain it, but the real nature of the mechanism is as yet unknown.

(3) Vertical Stratification of Sea Water in the Japan Sea (Tab. 13).

On the basis of vertical distribution of water temperature, salinity, and of oxygen and pH, we have classified, for the sake of convenience, five water-layers in the warm water-area of the Japan Sea, namely, the upper layer from the surface to 25 m. depth, the intermediate layer of 25 m.–200 m. depth, the lower layer from 200 m. to 500 m. depth, the deep layer from 500 m. to 1000 m. depth, and the bottom layer from 1000 m. depth to the sea-bottom.

Table 13. Oceanographical Elements averaged in the Japan Sea. ("Sôyô Maru", 1932).

Depth (m.)	θ °C	S ‰	σ_t	α	Stability 10^8 $E_{(CGS)}$		Vel. $\lvert\bar{v}\rvert$	O_2	$100\,O_2/O_2'$	pH	P_2O_5	N_2	SiO_2
							cm/sec.	cc/l.	%		mg/1m.^{3}	,,	,,
0	12.62	34.13	25.81	0.97467	700	400	18	6.31	101.8	**8.27**	10	7	646
10	12.14	34.20	25.93	0.97443	**1540**	**3267**	18	6.33	101.8	8.26	14	13	629
25	10.67	34.25	26.26	0.97420	1240	2760	17	**6.58**	**103.1**	8.24	25	21	686
50	8.68	34.32	26.64	0.97376	800	860	16	6.36	95.3	8.20	48	33	863
100	6.84	34.27	26.87	0.97342	520	80	12	6.25	89.5	8.14	69	86	1317
150	4.75	34.21	27.09	0.97300	400	40	8	6.22	85.7	8.07	90	115	1583
200	2.60	34.15	27.25	0.97257	110	—	5	6.21	80.7	7.97	129	151	1979
300	1.04	34.12	27.34	0.97205	30	0	—	6.05	75.1	—	—	—	—
400	0.46	34.10	27.36	0.97156	0	10	2	5.79	72.5	7.85	163	189	2592
500	0.29	34.12	27.38	0.97107	0	10	—	5.68	70.9	—	—	—	—
600	0.25	34.09	27.36	0.97060	(20)	0	1	5.58	68.9	7.81	191	222	2882
800	0.18	34.09	27.37	0.96977	0	0	0	*5.54*	68.2	7.81	206	244	3142
1000	0.15	34.10	27.38	0.96888	0	2	0	*5.54*	*67.9*	*7.78*	217	263	3216
1500	0.10	34.09	27.37	0.96669	0	0	—	*5.51*	*68.0*	7.81	225	276	3444
2000	0.10	34.08	27.36	0.96459	0	1	—	5.58	68.7	7.84	235	303	3838
3000	(0.16)	(34.29) ?	(27.54) ?	(0.96023)	—	—	—	5.63	69.5	7.87	(160)	345	3925
	All St. Averaged	,,	,,	,,	,,	St. 53	8 Sts. Averaged	All Sts. Mean	,,	42 Sts. Mean	19 Sts. (>1500m.) Mean	,,	,,

In the cold water-area we distinguished three water-layers, the upper layer from the surface to 25 m. depth, the intermediate layer from 25 m. to 200 m. depth, and the lower layer below 200 m. depth.

From the vertical distributions of silicate, phospate, and nitrogen as nitrate, and from the computed velocities, we can distinguish two layers one above and another below 200 m. depth.

A fact similar to what has just been described is that in the Japan Sea there exists a great difference in the hydrographical conditions above 200 m. and below it, whence the conclusion that by a series of observations down to a depth of 500 m. it may be possible to detect the general tendency of the three water layers, the upper, the intermediate, and the lower,

(4) The Water Characteristic of the Japan Sea.

The characteristic water in the Japan Sea at the time of our observations was a great water-mass occupying the water-layer below a depth of 200 m., with nearly uniform properties, that is, a water temperature of about 0°–1°C, salinity about 34.1 ‰, pH 7.85–7.9, dissolved oxygen 5.4–5.9 cc, and 100 $0_2/0_2'$ about 67–70 %, P_2O_5 200–250 mg/m^3, nitrogen as nitrate 250–350 mg/m^3, SiO_2 3000–4000 mg/m^3.

Comparing it with the sea water of the Pacific Ocean, the water of the Japan Sea below a depth of 200 m. shows a marked difference.

By the Tusima Strait threshold, which has an average depth of about 100 m., the characteristic water of the Japan Sea basin is completely separated from the water of the Pacific Ocean. The Tusima Strait as a threshold, limiting the distribution of the Japanese king-crab, herring, bonito, etc., corresponds to the famous Wyville-Thomson Ridge.

(5) A Speculation on the Origin of the Water Characteristic of the Japan Sea.

(i) Remarkable Abundance of Dissolved Oxygen.

The fact that remarkably large values of dissolved oxygen and high percentages of its saturation are met with in the Japan

Sea, points to active vertical mixing there. The abundance of dissolved oxygen, particularly in the seas off North Tyôsen and the south Siberian Coast, suggests that the source of supply is in these seas.

In the Japan Sea the vertical convection is in full swing in winter (from December to the following April). Especially in the water-area where the surface water temperature falls below 0°C, showing at the same time no marked vertical difference in salinity, it is reasonable to infer that an active convection current is formed in the following winter. The salty water, due to freezing near the coast in winter, by sinking down to lower depths is an important cause of the vertical convection, as already discussed by Mr. K. SUDA.[8]

The existence of water with low temperature and comparatively higher salinity might be explained by some of the water of high salinity sinking down at the time of freezing.

(ii) Vertical Stability.

Following Mr. K. SUDA,[8] the writer computed the stability at St. 53 in June and also the average stability for the Japan Sea (Tab. 13, Fig. 29). It will be seen from these computations, that the upper layer above 200 m. is stable, whereas below it the stability is nearly neutral, showing a uniform water-layer formed by active vertical mixing.

(iii) Salinity of the Characteristic Water.

The salinity of this water is slightly higher than that of the sea-water that occupies the upper layer of the northern part of the Japan Sea and remarkably lower than that belonging to the warm current-system. The salinity from surface to bottom is comparatively lower than in the seas on the Tyôsen side and higher than in the seas of the eastern part of the Japan Sea and its middle part.

(iv) Creeping of the North Tyôsen Cold Current.

From sectional observations we find that the sea-water with richly dissolved oxygen and low salinity, originating from the North Tyôsen sea region, seems to descend obliquely and creep into the base of the warm water-mass.

(v) Nutrient Salts for Planktons.

The vertical distribution of certain nutrient salts for plankton (P_2O_5, SiO_2, N_2O_5-N_2) in the cold water-area shows a higher value in the upper layer and a lower value in the lower layer than in the warm water-area.

From the facts above mentioned (i)-(v) we can therefore assume that the sea-water in the upper layer of the northern cold water-area is carried down to the lower layer, owing to the fact that its density increases as the result of cooling at the sea surface in winter, thus replenishing the characteristic water in the Japan Sea.

If this assumtion is correct, the yearly fluctuation of meteorological conditions (especially wind and air temperature) in winter in the northern part of the Japan Sea should have an important bearing on the yearly fluctuation in activity of the cold water mass characteristic of the Japan Sea.

The mechanism of the descent of the characteristic water and the renewal of the bottom water have already been discussed by Mr. K. SUDA.[8] However, the determination of them is left to future study.

(6) Correlation of the Distribution of Plankton with the Oceanographical Elements (Fig. 36).

The main features of the distribution of plankton are interpreted by Nathansohn's theory, that is to say, the quantity of plankton is abundant in some cold water-areas where the upwelling current carries water-mass rich in nutrient salts from the deep layer to the surface, while it is generally scanty in the warm water-area. The total quantity of plankton moreover is relatively large in the neritic water-area, while it is small in the water-areas remote from the coast.

The local distributions of P_2O_5 SiO_2, N_2O_5-N_2 resemble each other and show parallel variation in quantity. On the whole, in seas where P_2O_5, SiO_2, and N_2O_5-N_2 are abundant, combined with low water temperature and low salinity and rich in dissolved oxygen with a high percentage of saturation, we shall there find prosperous plankton life.

The total quantity of plankton present in a column of water from the surface to 50 m. depth shows parallel increase and

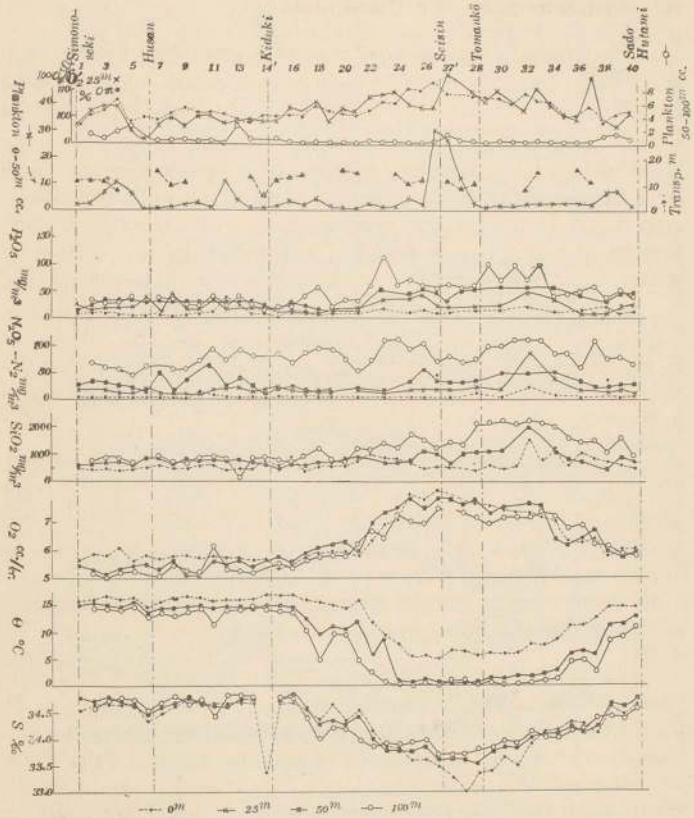


Fig. 36a. Quantity of Plankton and Some Oceanographical Elements Observed by "Sôyô Maru". (St. 1–40.)

decrease when compared with the quantity of nutrient salts at depths between 50 m. and 100 m., or the layer a little lower than the water column in question. It is also parallel to the values of percentage saturation of dissolved oxygen at depths of 25 m. and 50 m.

As to the idea that in the upwelling area of the lower water the degree of oxygen saturation should be small, actual conditions

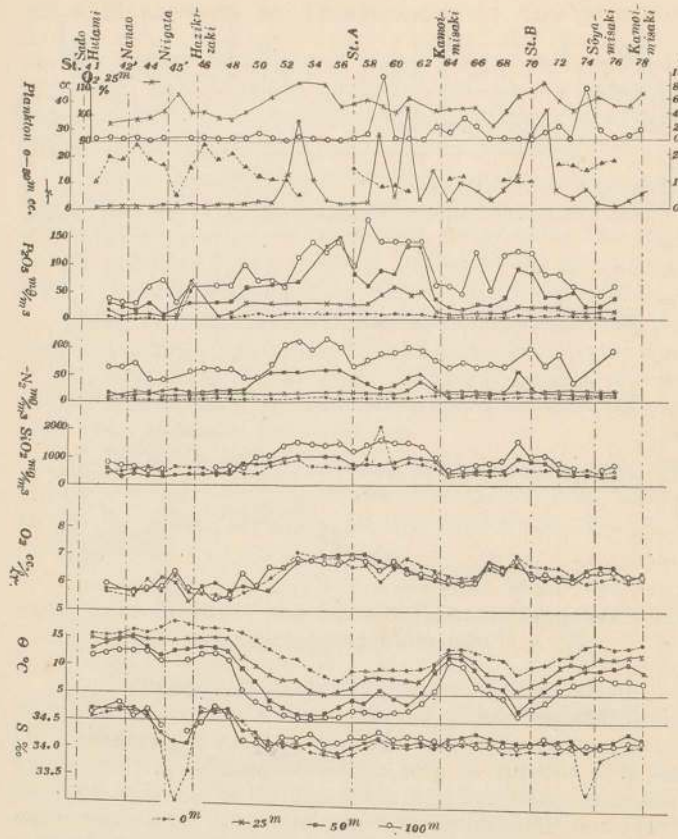


Fig. 36b. Quantity of Plankton and Some Oceanographical Elements Observed by "Sôyô Maru". (St. 41–78.)

are contrary to this expectation. The correct explanation may be that the supersaturation of oxygen is the result of brisk photosynthetic action on the part of the increased phyto-plankton forming the largest part of the total plankton.

Regarding the fact that instead of the area with maximum content of nutrient salts coinciding with the area of greatest concentration of plankton, it is displaced a little towards the

warm current-area, we may interpret it by supposing that in the area of greatest plankton concentration, the consumption of the nutrient salts is too great for sufficient replenishment. In the western cold water-area the supply of the nutrient salts is in excess.

The total quantity of plankton is remarkably large in the water-layer above 50 m. depth compared with lower depths. The horizontal variation of plankton density is also very large at the same layer from the surface to 50 m. depth when compared with the lower layer, which shows a nearly uniform horizontal plankton density.

The mean density of plankton in the water column from the surface to 50 m. depth is 8 times that in the water column from 50 m. to 100 m. depth and 16.5 times that in the water column from 100 m. to 200 m. depth.[15]

As already mentioned, the zone of maximum photosynthetic action may be considered to lie in the layer from the surface to about 25 m. depth, as previously mentioned. By plotting the iso-lines for depths with 100 % saturation of oxygen on a chart, it is possible to estimate the local distribution of plankton density, because the depth corresponds to the thickness of the vertical distribution of plankton for normal photosynthetic action when in a state of equilibrium (neglecting the influence of water movement).

(7) Trawl-Net Fishing in the Yellow Sea and Hydrographical Conditions there.

The following reports of catches made with trawl-nets during two hours have been made available; namely, at six fishing grounds from 5th to 9th of June by the "Hatutaka Maru", at nine fishing grounds from 1st to 7th of June by the "Hisyun Maru", and at two fishing grounds in early June by the "Syôhô Maru".

Upon comparing the distribution of the various kinds of fish caught with the hydrographical conditions that prevailed in early June, 1932, we find that in water-area *A*, west of Kyûsyû, where the bottom is deeper than 100 m., most of the fish caught was "Eso" (*Saurida argyrophanes*) and certain kinds of "Tahi"

Pagosomus major (*T. & S.*)), while in water-area *C*, in the western and northern part of the Yellow Sea and in the western part of the East China Sea, influenced considerably by fresh water, large catches made of " Siro Guti ", " Karei " (a kind of flat fish), and " Ehi ". In water-area *B*, intermediate between areas *A* and *C*, and extending from north to south in the central part of the Yellow Sea, much " Tatiuwo " (Hair-Tail) was caught. Although " Ika " (cuttlefish) and " Kanagasira " (*Lepidotrigla alata*) were caught in all the fishing grounds, the " Ika " becomes increasingly abundant towards the open sea while the " Kanagasira " is relatively abundant in the shallower regions of the seas.

Water area (*A*) has a high salinity of over 34.5 ‰ in the bottom layer, with a transparency exceeding 15 m., the colour of the water being deeper than III of Forel's scale. Water-area *C*, which has comparatively little salt has a transparency less than 10 m., while the colour of the water is paler than V in Forel's scale. Water-area *B* has a transparency of 10 m.–15 m. and colour III–V.

(8) Fishery Conditions, especially for Sardine and Mackerel, as related to Hydrographical Conditions.

The reader is referred in the Semi-annual Reports of Oceanographical Investigation No. 50. for full data relating to fisheries.

For the isotherms and the daily variations of water temperature, we find that the fishing season for sardines ("Ôba-Iwasi") begins at the time when the water temperature is about 11°C.

There was a notable decline in the catch of " Ôba-Iwasi " this year on the side of Japan proper, with a shortened fishing season, while in the seas adjacent to Tyôsen, conditions were more favourable than in a normal year, although very unfavourable compared with last year (1931).

On the side of Japan Proper, fishing this season in the northern part of Noto-Peninsula was more favourable than in the southern. This condition is explained by supposing (1) that the Tusima Warm Current was then flowing over a relatively wider area off the coast than in normal years; and (2) that it was flowing with unusually low water temperature in the North Tyôsen sase and in the southern part off the seas on the side of Japan

Proper; and (3) that the sardine shoals were generally scanty in the seas on the side of Japan Proper in this year.

Since the fishing grounds for sardine and mackerel on the side of Japan proper are close to the coast the daily catches are fairly continuous during the fishing season. In contrast to this, in the seas adjacent to the east coast of Tyôsen (North Tyôsen in particular), as the fishing ground are remote from the coast, the catches fluctuate considerably on account of the intermittent migration of the fishes. The reason for this is that, although on the side of Japan Proper, the Tusima Current is always flowing near the coast, a branch of that current, the East Tyôsen Warm Current, flows comparatively distant from the coast. In summer, however, the latter comes nearer the coast. Since the isolated water-mass that is produced by small vortical currents on the boundary between the warm and cold water-masses, sometimes get detached from the boundary and carried towards the coast, it is reasonable to suppose that shoals of fishes, such as sardine and mackerel, etc., that are caught in the water-mass, come and go from the fishing grounds near the coast at irregular intervals.

The low water temperature in the North Tyôsen sea-region, lower this year than in a normal year, has delayed the migration of sardines and, to a greater extent, that of mackerel.

In the Yellow Sea, owing to the weak development this year of the north-going branch of the warm current, the season for mackerel fishing was delayed in the western sea off Tyôsen.

The mackerel fisheries this year was generally poor, particularly in the southern part of the Japan Sea on the side of Japan Proper, although the northern part reported a fairly good catch. The mackerel fisheries in the seas on the Tyôsen side was in general relatively more favourable than in the seas on the side of Japan Proper.

It is noteworthy that the large catches of mackerel in Wakasa Bay during March-April, coincide with the flow in full volume and strength of the warm current in the beginning of the year, during which an abnormal high temperature was reached towards the north of the sea along Japan Proper.

At the time of our investigations an extraordinary phenomenon was observed by the Tottori Fisheries Experimental Station with respect to mackerel fishing. It appears that the mackerel

shoals sank down into the lower layer where they were caught by bottom gill-nets, while on the otherhand shoals supposed to belong to the same swarm of mackerel that were caught on the side of Japan Proper, were found in the upper waters in the vicinity of Uturyô Tô. Such an abnormal fishery condition may be correlated with abnormal hydrographical conditions, in which the influence of the lower cold water flowing in full volume and strength in the seas adjacent to Tyôsen had extended to the southern part of the seas along Japan Proper and also with the fact that the Tusima Current- axis was running unusually remote from the coast.

Concluding Remarks.

Notwithstanding the preliminary character of the present simultaneous hydrographical surveys of the Japan Sea and its adjacent waters that were made in May and June, 1932, we have obtained some reliable knowledge of actual hydrographical conditions for a period around the fifth of June, besides certain important facts that could be correlated with the condition of the fisheries during that interval.

The need being keenly felt of another survey, in autumn and in winter, of the same water-area on lines similar to those here described, for the purpose of clearing up certain questions relating to both fisheries and hydrographic conditions, a second simultaneous survey to cover a period around October 5 is now in course of preparation.

We may further state that, since the Tugaru Warm-Current, which captures the greater part of the stream-lines in the spread waters of the Japan Sea, considerably affects the hydrographic conditions of the wellknown fishing grounds south of Hokkaidô, in the Pacific Ocean, hydrographic investigations of the Japan Sea area will have much wider significance than may appear at first sight.

In concluding this paper, the writer wishes to express his sincere thanks to the crews of all the research boats that participated in our surveys for their zealous cooperation in our work, especially to the crew of the "Sôyô Maru", and individually to Messres. T. Yamasita, S. Usioku, N. Watanabe; and also to Prof. T. Terada for his kind advices given in preparing this report.

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Postscript:

(1) Banks, north of "Yamato-Tai", west of (A) (see p. 24) has been brought in light lately. Refer to Hydrographical Bulletin p. 427, 1933.

(2) From the second simultaneous survey carried out for a certain period about Oct. 5 in 1933 the position of (B) (see p. 24) may be corrected.