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On the Abyssal Circulation in the Northwest Pacific Area

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Hitherto in the Northwest Pacific Area including its adjacent seas deep sea surveys were carried out by many research boats after the famous Challenger Expedition, Vitiaz, Carnegie Expeditions unto the recent Baird, Challenger II, Vitiaz II and in addition to them several Japanese research vessels such as "Komahasi" and "Mansyū" belonging to the Hydrographic Department, "Sōyō-maru", "Tenyō-maru" (Fisheries Agency), "Ryōfū-maru" (Japan Meteorological Agency), "Umitaka-maru" (Tokyō Univ. of Fisheries) and "Oshoro-maru" (Hokkaidō Univ.) etc.

However, the data obtained by the hydrographic casts down to the depths below than the layer of 1,500 m depth are not so abundant nowadays as to discuss the deep sea circulation precisely. Following the classical theory on the meridional circulations in the three great oceans proposed by A. Merz, A. Defant and G. Wüst[1)] (established by world-known "Meteor" Expedition) formerly the author has studied the patterns in the western Pacific and discussed the Oyashio Under-Current (a peculiar subsurface Subarctic Current)[2)] creeping beneath the Kuroshio Current and extending unto the southern seas of Japan. Recently the intermediate current has been studied by some oceanographers in Japan on the theory after H. U. Sverdrup (as shown in the well-known book "The Oceans", 1949). At this occasion the author is deeply interested to the new theory proposed by H. Stommel and others.[3)] The experiments using the Swallow's neutral-buoyancy float[4)] may throw most promisable (or a decisive) high light to discover the actual state of subsurface deep currents neighbouring to Japan in near future. Of course on the bottom currents in the Pacific Ocean a few works were presented in the paper of a Japanese Oceanographer, Saburō Kishindo[5)], basing on the distribution of potential temperature and dissolved oxygen *etc.* and the papers by G. Dietrich, G. Wüst[7)] and Van Veen *et al.* The recent model of world-wide abyssal circulation by H. Stommel, A. C. Redfield and others[3)] shows us an impressive clear pattern fitting to the hitherto researches.

In the following the author wishes to state briefly some details of his results studied in the northwestern Pacific (north to thd Subarctic Convergence) especially on the basis of the deeper surveys below than the 1,000 m depth, including the recent data obtained by NORPAC PROJECT (1955).

1. The Stratification of Water Masses

In the subarctic northern seas and ocean in winter the convectional mixing in the upper layer shows a conspicuous characteristics of the stratification. In the northern sea-region on the continental side of Japan Sea the winter convection is very intense from sea surface unto the deepest zone of sea basin over 3,000 m depth forming a remarkably homogeneous deep water mass (water temperature 0–1°C, salinity 33.95–34.15‰ dissolved oxygen 5.7–6 cc/1 and its saturation percentage 70–80%). Also in the shallow Yellow Sea the convection effected by cold

Table 1. Typical Hydrographic Data.

JAPAN SEA				YELLOW SEA			EAST CHINA SEA				SOUTH CHINA SEA			
St. 27 SŌYŌ-MARU 1933 X. 13 41°32′30″N. 136°03′00″E.				MISAGO-MARU 1932 VI. 4. 38°17′N. 122°56′E.			SŌYŌ-MARU St. 122 1939 VII. 24 25°33′N. 125°00′E.				SŌYŌ-MARU St. 102 1939 VII. 15 20°47′N. 118°02′E.			
m	T°C	S‰	O_2(%)	m	T°C	S‰	m	T°C	S‰	O_2(%)	m	T°C	S‰	O_2(%)
0	15.20	33.64	98.3	0	14.8	31.49	0	27.50	34.54	115	0	29.20	33.53	100
10	15.09	33.64	99.2	5	14.3	31.53	5	27.48	34.47	109	5	29.11	33.48	106
25	15.06	33.64	98.7	10	12.0	31.78	10	27.46	34.52	105	10	29.13	33.49	106
50	1.92	33.62	89.8	25	5.8	31.87	25	27.26	34.61	117	25	29.10	33.58	106
100	0.52	34.16	82.5	50	5.5	32.03	50	26.40	34.63	108	49	27.07	33.71	112
150	0.43	34.00	82.0	60	5.3	32.03	75	24.77	34.83	108	66	25.15	34.04	108
200	0.34	34.11	81.9	(bm)			100	23.68	34.88	104	88	23.19	34.38	90
300	0.26	34.11	79.8				144	21.66	34.96	97	148	19.09	34.61	73
400	0.20	34.13	73.7				192	18.87	34.87	87	197	17.00	34.67	69
500	0.14	34.05	73.0				288	16.51	34.69	84	295	12.59	34.43	64
600	0.14	34.11	73.0				364	14.47	34.58	80	368	10.15	34.45	48
784	0.14	34.07	73.5				455	11.55	34.36	67	460	9.02	34.40	45
976	0.11	34.04	72.8				544	9.38	34.31	55	552	7.93	34.42	37
1,467	0.11	34.07	71.8				768	6.00	34.33	35	761	6.23	34.43	35
1,952	0.12	33.96	72.0				960	4.63	34.42	29	951	4.74	34.56	35
2,928	0.23	34.00	72.8				1,441	3.93	34.47	27	1,427	2.87	34.61	36

winter monsoon is almost completed all over to the bottom. However the circumstances in the Okhotsk Sea and Bering Sea with their adjacent waters of Kurile Islands and Aleutian Islands are thoroughly different, indicating in winter upper low water temperature (katotherm), low salinity to the depths about 150–200 m from sea surface, and in summer the intermediate temperature minimum (dicho-

Table 2. Typical Hydrographic Data.

OKHOTSK SEA			OKHOTSK SEA				BERING SEA			ALEUTIAN			N. PACIFIC		
ŌDOMARI			SŌYŌ-MARU				OSHORO-MARU			OSHORO-MARU			KOMAHASHI		
1939			1935 St. 65				1955			1955			1936		
IV. 26			VIII. 21				VI. 26			VII. 1			VI. 12		
46°27′N.			46°28′N.				51°43′N.			53°14′N.			41°20′N.		
144°45′E.			145°24′E.				160°30′E.			178°40′E.			68°17′E.		
m	T°C	S⁰/₀₀	m	T°C	S⁰/₀₀	O_2(%)	m	T°C	S⁰/₀₀	m	T°C	S⁰/₀₀	m	T°C	S⁰/₀₀
0	−1.19	32.25	0	15.0	32.29	107	0	6.0	32.47	0	5.9	33.38	0	12.82	34.33
10	−1.29	32.30	10	14.79	32.29	103	10	5.18	32.54	10	5.56	33.24	10	12.84	34.33
25	−1.33	32.30	15	13.59	32.45	—	25	3.01	33.08	24	5.36	33·26	25	12.74	34.33
50	−1.48	32.92	25	7.79	32.57	129	50	−0.57	33.03	49	4.38	33.31	50	12.49	34.33
94	−1.59	33.01	35	2.70	32.77	—	75	−0.64	33.15	73	3.16	33.39	100	11.38	34.33
143	−0.62	33.19	50	0.33	32.99	94	100	−0.34	33.21	95	3.11	33.44	150	10.35	34.25
196	0.71	32.81	75	−0.59	33.08	—	150	0.35	33.33	147	3.02	33.42	200	8.98	34.21
279	0.88	33.48	100	−1.13	33.12	92	200	0.63	33.44	191	3.52	33.64	300	7.34	33.95
376	0.81	33.83	125	−1.07	33.17	—	295	2.91	33.75	266	3.71	33.87	400	5.74	33.96
			150	−0.89	33.24	83	393	3.40	33.91	373	3.65	34.11	500	4.72	33.96
			200	0.13	33.35	72	488	3.50	34.07	450	3.51	34.18	600	4.26	34.13
			300	1.04	33.12	(94)	583	3.46	34.16	541	3.46	34.25	800	3.70	34.14
			400	1.01	33.69	51	780	3.07	34.36	723	3.27	34.40	1,000	3.15	34.33
			500	1.41	33.78	43	970	2.86	34.36	918	2.93	34.45	1,200	2.77	34.40
			600	1.72	33.93	—	1,151	2.83	34.49	1,136	2.65	34.51	1,500	2.42	34.27
							1,440	2.56	34.54	1,428	2.30	34.58	2,000	2.02	34.33
	St. 64		768	1.82	33.96	30							3,000	1.58	34.60
	46°48′N.		960	2.18	34.13	18	1,989	1.86	34.63				4,000	1.50	34.60
	146°32′E.		1,440	2.22	34.43	18							5,000	1.60	34.61
	VIII. 21		1,929	2.01	34.54	19	VII. 1		54°30′N.						
	1935		2,893	1.88	34.54	26			170°33′E.						

therm) zone from nearly 50 to 200 m depths, and throughout the year mesothermal layer exists (a feeble temperature maximum) from the 300 m to 500 m depth. Below the 600 m depth the distributions of water temperature and salinity tends to show nearly homogeneous state in the horizontal section. Commonly beneath the mesothermal layer we can find the oxygen-minimum layer at about 800–1,000 m depths which suggests us the existence of a very stagnated layer or of the most active decomposition layer of fallen organic materials (consuming dissolved oxygen from the surrounding sea water). Down to the abyssal depth from nearly 1,200 m depth to 5,500 m depth the water temperature lies in the range of 1.4–2.5°C and the salinity in the range of 34.4–34.7⁰/₀₀. (Based on mainly "Komahashi's data".)

2. The Formation of Dichothermal Layer

To the end of April the vertical convection takes place vigorously, decaying in May (spring season) gradually it forms the dichothermal stratification mainly due to the insolation on the surface layer and partly due to the advection of the southern warm water accelerated by the reversal monsoon drift.[6]

Unto the bottom of the dichothermal water (at about 200 m depth) it shows the salinity as comparatively homohaline (*ca* 33.0–33.5‰) and richly dissolved oxygen (>6 cc/l).

As the stratification developes with the march of the warmer season the water temperature becomes higher and the salinity becomes lower in the surface layer.

During autumn season as the water is cooled down and the salinity in the upper layer rises stratification becomes extinct due to the increasing convectional depth.

3. The Existence of Mesothermal Layer in the Subarctic Area

The origin of mesothermal water in the polar seas is considered as in usual way due to the subsidence of the subsurface warm water. In our case from the eastern or southeastern areas the oblique subsidence of warm water seems to occur (*e.g.* see Fig. 1) along the isopycnic surface (isentropic surface) of about $\sigma_t = 2720$ corresponding to water temperature of 3.6°C and salinity of 34.1‰. The

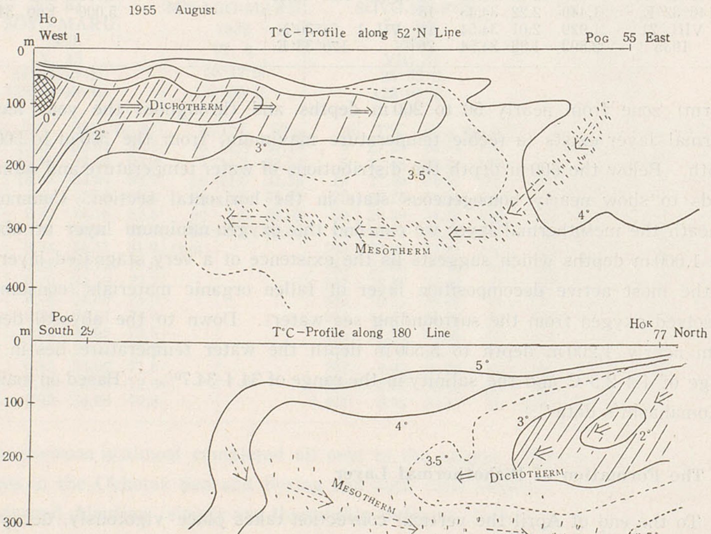

Fig. 1.

mesothermal water in the northwestern Pacific shows commonly its temperature (3.0-3.8°C) and its salinity (33.8-34.2‰) in the depths of 300-600 m.

Beneath the bottom of the dichothermal layer to the core depth of the mesothermal layer as its salinity increases suddenly the quantity of dissolved oxygen decreases down to the depths of 300-400 m. Below the mesothermal layer the dissolved oxygen tends to decrease to its minimum.

On the polar front along the Subarctic Convergence the oblique subsidence of mesothermal water seems to occur in laminar slow motion with the contrast to the vertical convection above the depth of dichothermal bottom.

We can find the mesothermal layer even in winter. Detailed analysis is left in future.

The dichothermal layer coincides almost always with the intermediate minimum layer of salinity (the intermediate layer) in the sea-region south of polar front (Subarctic Convergence).

4. Some Further Considerations

The secular variations of the characteristics of dichothermal and mesothermal layers with their deeper layers are very fascinating problem to us. The conditions in the warmer years and colder years may be different concerning to the water temperature, salinity and dissolved oxygen, and may indicate the variation of oceanic climate. The arctic and antarctic warming in late years (or century) shall bring the higher sea level due to the melted polar ice (sea-ice and icebergs) and the increased precipitation over the polar regions. As their consequences salinity shall be lowered in the water masses of the oceans (from sea surface to abyssal bottom in the long run) and the water temperature shall be risen over the broad sea-areas in the upper layer and shall be lowered generally in the deeper layers.

Some evidences were obtained by the present author (which shall be reported later).

Under such a predicted condition the abyssal circulation may be weakened in future which is important not only to the biological productivity in the deep oceans but also to the disposal problem of atomic wastes.

Compared to the abundant quantity of dissolved oxygen and its saturation of the deep water in the Japan Sea, those in the Pacific Ocean, Bering sea and Okhotsk Sea are very poor, and those in the East China Sea and South China Sea are the medium of them. The degree of aeration (or oceanic ventilation) in the abyssal sea basin should be studied more in detail.

The influence on the biosphere by such conditions, especially by their secular variations, are interesting and important problem.

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