

On the Distributions of Dissolved Oxygen and Nutrient Salts in Tuna Fishing Grounds of the Central Tropical Atlantic.

By

Arao TSURUTA, Satoru TAWARA and Tadashi UEDA

Introduction

The survey referred in the present report was made during the period between November 24th, 1965 and January 10th, 1966 along the meridional section of longitude 25°W from latitude 20°N to 20°S which is located in the central Atlantic Ocean by the training ship *Koyo Maru*. Twenty-three oceanographic stations covered 2400 nautical miles (Table 1 and Fig. 1).

This investigation was carried out as a part of the survey in the tuna fishing grounds. Oceanographic observations were done for 17 casts from the surface to a depth of 1200 m, and water temperature was measured and water samples were collected. At the same time zooplanktons were collected, using Indian Ocean standard net, from a depth of 200 m to the surface. Moreover the tuna longline fishings were performed at 13 stations and every time 180 baskets with frozen saury were used as baits. Some of the results of this investigation, including the relationship between the water temperature, the distribution of zooplankton biomass and the tuna fishing condition, were previously reported (TAWARA et al. 1966).

Therefore the present report deals with the distributions of dissolved oxygen, phosphate-P and silicate-Si. The contents of dissolved oxygen were measured after WINKLER's method, and phosphate-P and silicate-Si were measured after electrocolorimetric methods using the autorecording photoelectric filter photometer (Tokyo-Koden Model 7D).

We like to express our sincere thanks to Yoshihiro MAENO, Ryoji IIBOSHI and Shunji HAMADA for their cooperation in the preparation of the data. Our appreciation are due to Drs. Isao MATSUI, Reizo ISHIYAMA and Takuo CHIBA, who are professors of Shimonoseki University of Fisheries, for their useful advices and giving us an opportunity to board on the ship. We are grateful to Captain Goro SAKURAI, officers and other crew and students who gave us their help in various ways.

* Contribution from the Shimonoseki University of Fisheries, No. 500
Received Feb. 13, 1967

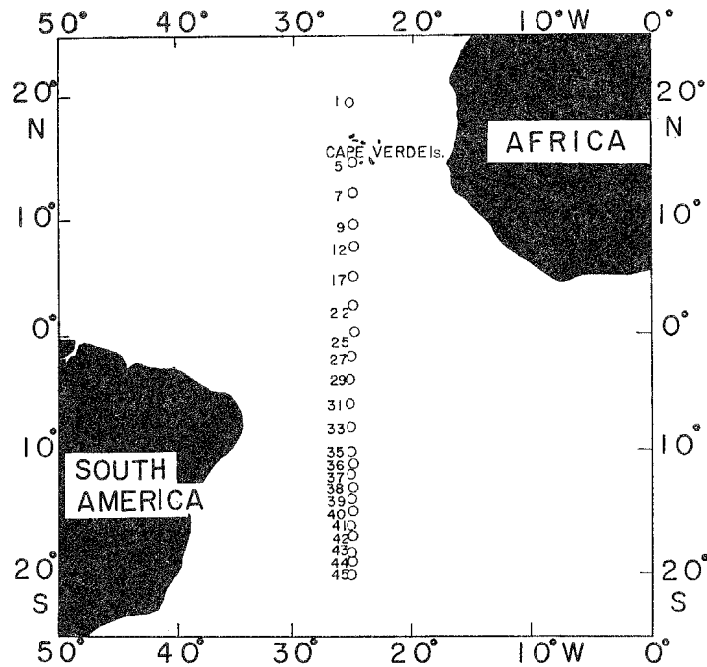


Fig. 1. Positions of hydrographic stations in the central Atlantic.

Results of analysis

Vertical distributions of dissolved oxygen, phosphate-P and silicate-Si.

Dissolved oxygen.

The vertical distribution of dissolved oxygen at the surveyed area are shown in Fig. 2 and types of the vertical change of dissolved oxygen are classified into three groups.

Stations 1~17 (Fig. 2, A).

The content of dissolved oxygen in the surface layer was 4.5~5.0 ml/l and the remarkable chemocline in which dissolved oxygen decreased at the rate of 0.3~0.4 ml/l per 10 m was perceived in a layer between 50 m and 100 m, and the values in the chemocline differed about 3 ml/l from those at the surface. At a layer between 400 m and 600 m the contents of dissolved oxygen attained to the minimum value at 1.5~2.0 ml/l, and below this layer dissolved oxygen gradually increased with the depth. At a depth of 1200 m dissolved oxygen reached 3.8~4.0 ml/l.

Stations 22~39 (Fig. 2, B).

At the surface the contents of dissolved oxygen were 4.7~4.8 ml/l, but in a layer between 25 m and 75 m at the stations 36 and 39, dissolved oxygen increased a little. At a depth of 100 m the chemocline was obscure. At a depth of 400 m the content of dissolved oxygen attained to the minimum value at 2.0~2.6 ml/l, and in the deeper

Table 1. Data on dissolved oxygen, phosphate-P and silicate-Si of water in the central Atlantic Ocean (November 24th, 1965-January 10th, 1966).

No.	Station	Date	Dissolved oxygen (ml/l)																				Phosphate-P (mg-w/L)																
			0 m	10 m	25 m	50 m	75 m	100 m	125 m	150 m	200 m	250 m	300 m	400 m	500 m	600 m	800 m	1,000 m	1,200 m	0 m	10 m	25 m	50 m	75 m	100 m	125 m	150 m	200 m	250 m	300 m	400 m	500 m	600 m	800 m	1,000 m	1,200 m			
1	19°48 N	25°15 W	1965 Dec	21	5.02	4.85	4.70	4.23	2.95	2.25	2.45	3.16	2.61	2.55	2.45	2.31	2.12	2.56	3.25	3.95	0.27	0.31	0.21	0.22	0.35	0.28	0.33	0.22	0.41	1.02	1.01	1.23	1.50	1.29	1.22	1.64	1.56		
5	15 00	24 00	25	4.98	4.65	4.12	2.25	1.38	1.69	2.12	2.26	2.06	1.78	1.59	1.69	1.96	2.50	3.09	3.95	0.27	0.30	0.16	0.26	1.07	1.61	1.61	1.33	1.56	1.35	1.62	1.59	1.76	1.63	1.71	1.76	1.86			
7	15 00	23 00	26	4.69	4.81	5.37	1.73	1.70	1.99	2.11	2.14	2.02	1.78	1.67	2.31	1.65	2.28	2.95	3.43																				
9	09 40	21 00	27	4.72	4.81	3.90	2.39	2.57	2.41	2.91	2.42	2.36	2.45	1.51	1.11	1.58	2.42	3.21	3.51	0.16	0.21	0.09	0.09	1.29	1.33	1.34	1.34	1.42	1.14	1.50	1.59	2.02	1.92	2.15	1.80	1.80			
12	07 00	25 00	28	4.73	4.73	4.38	3.41	2.89	2.72	3.28	3.35	3.30	3.20	2.50	1.59	1.81	2.72	3.22	3.59	0.23	0.26	0.12	0.26	0.63	0.95	1.12	1.14	1.21	1.35	1.51	1.75	1.45	1.97	2.40	1.80	1.80			
17	05 00	25 00	28	4.65	4.71	4.75	4.32	3.09	2.42	2.56	3.19	2.68	3.35	1.82	2.91	2.11	3.17	3.47	3.79	0.10	0.15	0.10	0.13	0.21	0.29	1.17	1.25	1.12	1.40	1.25	1.73	1.47	1.95	2.05	1.90	1.70			
21	02 00	25 00	28	4.82	4.72	3.52	2.77	2.35	2.66	2.29	2.35	2.53	2.18	2.56	2.94	3.32																							
23	09 12	26 00	30	4.62	4.65	4.71	4.90	3.30	3.99	3.62	3.05	3.47	2.79	3.02	3.18	3.05	3.83	3.89	4.11	0.22	0.29	0.18	0.23	0.37	0.75	0.99	1.11	1.25	1.24	1.51	1.43	1.81	1.93	1.92	1.85	1.45			
29	01 57 S	25 14	31	4.65	4.77	4.78	4.67	3.89	2.99	3.05	2.80	2.50	2.28	2.35	3.42	3.66	3.59	3.82	4.16	0.21	0.16	0.18	0.21	0.20	1.12	1.19	1.26	1.23	1.34	1.58	1.51	1.73	1.85	1.91	1.87	1.76			
29	03 51	25 19	1966 Jan	2	4.78	4.83	4.74	4.07	3.09	2.44	2.69	2.50	2.76	2.41	3.07	3.18	3.09	3.73	3.36	4.00	0.50	0.20	0.18	0.20	0.47	1.02	1.45	1.31	1.25	1.30	1.35	1.40	1.50	1.77	1.90	1.79	1.82		
31	06 00	25 19	3	4.80	4.81	4.79	4.66	4.56	3.60	2.50	3.33	2.25	2.69	2.23	2.29	2.78	3.71	3.45	3.57	0.29	0.32	0.19	0.29	0.18	0.32	0.91	1.13	1.34	1.51	1.85	1.69	2.32	1.95	1.80	1.91	1.99			
33	02 00	26 12	4	4.77	4.72	4.28	1.61	4.89	4.51	3.80	2.36	2.23	2.25	2.29	2.28	2.85	3.49	3.91	4.61	0.27	0.21	0.17	0.16	0.16	0.24	0.37	0.75	1.40	1.71	1.76	1.77	1.99	2.04	2.14	1.99	1.60			
35	10 03	26 12	5	4.78	4.73	4.75	4.95	3.05	4.99	4.53	3.52	2.54	2.15	2.27	2.49	2.82	3.61	3.93	4.34	0.26	0.16	0.16	0.15	0.17	0.21	0.22	0.34	0.92	1.19	1.61	1.83	1.60	1.91	1.89	1.81	1.67			
36	11 13	26 59	5	4.72	4.69	4.91	5.13	5.03	4.94	4.72	3.95	3.65	2.45	2.77	2.67	3.05	3.09	3.90	4.46	0.21	0.12	0.19	0.15	0.15	0.16	0.21	0.37	0.74	1.17	1.51	1.75	1.92	1.99	1.86	1.71	1.69			
37	12 00	26 17	6	4.73	4.66	4.86	5.14	5.26	4.68	4.67	3.50	3.35	2.43	2.72	3.52	3.78	3.97	3.98	4.40	0.22	0.21	0.28	0.17	0.20	0.22	0.31	0.44	0.83	1.15	1.51	1.84	1.94	1.96	1.96	1.91	1.77			
38	10 00	26 00	6	4.77	4.76	4.94	5.08	5.09	5.02	4.58	4.16	3.32	2.73	2.56	2.95	3.45	3.58	4.02	4.30	0.25	0.27	0.22	0.22	0.22	0.22	0.22	0.28	0.29	0.32	0.79	1.15	1.35	1.58	1.82	1.83	2.02	2.02	1.69	
39	14 01	25 14	7	4.79	4.75	4.80	5.10	4.67	5.01	4.81	4.61	4.25	3.89	3.33	3.71	3.55	3.78	3.66	0.22	0.22	0.22	0.21	0.23	0.39	0.90	0.33	0.59	0.81	1.15	1.51	1.91	1.95	2.02	1.82	1.72				
40	15 00	25 01	7	4.71	4.73	4.82	5.14	5.10	5.00	4.82	4.56	4.19	3.86	3.62	4.31	4.39	4.23	4.31	4.30	0.21	0.21	0.21	0.19	0.16	0.22	0.22	0.29	0.33	0.75	0.83	1.03	1.44	1.75	1.92	1.99	1.95	1.70		
41	16 01	25 17	8	4.89	4.85	4.80	4.95	5.26	5.06	4.76	4.60	4.11	4.03	3.74	3.61	4.09	4.29	5.03	4.42	0.20	0.21	0.22	0.20	0.25	0.34	0.27	0.26	0.60	0.89	0.99	1.37	1.35	1.70	2.07	1.96	1.76			
42	17 00	25 09	8	4.74	4.75	5.05	5.15	4.93	4.83	4.91	4.77	4.66	4.39	3.98	3.97	3.86	4.09	4.20	4.46	0.22	0.32	0.32	0.22	0.22	0.23	0.25	0.38	0.39	0.42	0.64	0.86	1.27	1.80	1.95	1.80	1.55	1.70		
43	18 15	25 05	9	4.77	4.75	4.79	4.98	5.14	4.99	4.99	4.65	4.71	4.51	3.77	3.83	3.32	3.62	4.29	4.83	0.24	0.28	0.25	0.26	0.27	0.27	0.28	0.29	0.42	0.55	0.71	1.32	1.66	1.86	1.98	1.95	1.66			
44	19 00	25 02	11	4.76	4.82	4.82	5.06	5.07	5.06	5.02	4.81	4.72	4.52	3.89	3.57	3.76	4.12	4.47	4.81	0.25	0.25	0.22	0.21	0.21	0.23	0.23	0.25	0.40	0.51	0.63	1.15	1.66	1.65	1.89	1.91	1.99			
45	20 02	25 11	10	4.50	4.52	4.92	5.16	5.15	5.14	4.94	4.69	4.30	4.67	4.37	4.02	3.94	4.26	4.41	4.53	0.24	0.24	0.25	0.25	0.21	0.21	0.26	0.25	0.42	0.57	0.75	0.89	1.35	1.72	1.97	1.90	1.77			

Silicate-Si (µg-at/L)																
0	10	25	50	75	100	125	150	200	250	300	400	500	600	800	1,000	1,200
1.0	3.6	4.9	6.6	8.1	9.5	10.9	12.2	14.8	17.4	19.7	23.7	27.1	30.5	35.6	39.8	44.4
3.0	5.9	8.7	14.2	18.4	21.1	21.8	22.1	22.7	25.2	28.1	31.3	33.4	35.4	39.4	41.4	39.2
21.2	9.6	8.9	11.6	12.9	15.2	15.5	17.9	13.5	15.8	15.3	24.1	35.5	23.9	24.3	33.8	23.9
8.5	6.4	8.1	12.9	13.5	15.9	18.0	19.0	19.9	20.0	20.0	20.9	22.7	25.7	22.4	44.5	28.6
22.8	12.3	4.4	3.6	6.0	11.5	12.2	14.4	16.3	17.8	19.1	20.0	20.0	21.5	24.4	44.3	20.3
9.0	4.4	2.5	1.3	2.0	3.5	5.8	7.5	11.5	14.4	17.0	20.7	22.7	25.5	29.1	35.8	22.2
5.5	6.5	6.1	4.5	5.5	14.3	16.1	17.0	19.0	20.3	24.2	31.1	34.8	37.6	41.7	45.8	41.8
3.0	5.5	3.4	3.9	8.1	8.4	8.5	9.9	15.4	16.1	15.6	17.5	22.2	26.7	42.1	45.8	41.0
19.6	3.7	4.4	2.5	7.5	6.0	14.6	17.3	19.6	21.1	28.1	32.0	35.7	39.6	42.6	55.1	42.7
5.5	6.7	7.7	7.8	7.5	9.9	9.7	12.2	18.2	23.5	29.2	32.9	38.4	44.3	52.7	54.4	40.4
13.0	6.0	6.7	7.2	11.8	9.4	9.2	11.0	13.0	20.0	25.4	31.1	36.2	41.4	51.2	37.0	47.5
15.5	9.0	16.7	11.3	10.1	9.8	9.9	10.4	11.6	14.4	20.3	29.1	33.5	37.4	41.8	44.7	41.7
21.4	9.5	8.5	9.7	6.6	5.0	6.0	6.8	12.5	15.6	17.8	22.2	41.8	22.7	46.1	49.2	59.6
9.0	6.2	8.9	17.5	8.7	8.2	10.1	12.4	14.9	15.3	24.0	34.3	40.8	44.4	50.8	54.6	51.6
22.5	9.6	10.6	12.4	12.6	13.8	14.4	14.4	12.2	14.3	19.1	30.8	32.2	36.6	54.2	38.2	32.2
11.2	2.3	9.0	11.9	7.8	7.5	8.2	8.0	9.1	11.2	14.2	21.5	32.7	41.8	53.8	56.8	55.0
12.5	7.5	11.0	11.3	10.7	9.5	6.9	6.5	11.6	15.0	18.7	21.9	22.4	24.9	42.0	58.6	52.7
11.7	9.1	9.1	6.0	6.7	8.4	11.0	12.0	11.6	14.6	15.2	21.4	41.5	44.6	46.2	59.1	52.6
14.2	12.5	10.5	9.7	11.0	10.3	11.5	13.4	11.3	11.5	13.9	22.3	31.9	37.6	54.1	60.7	49.3
22.2	19.0	19.0	18.1	16.2	13.0	15.7	11.2	11.3	11.6	11.8	17.7	31.1	33.3	56.1	66.1	64.6
19.7	3.7	6.3	3.5	6.2	7.8	9.0	6.6	8.6	9.2	5.5	13.5	22.2	20.7	48.0	55.7	51.9

layer dissolved oxygen gradually increased with the depth. It attained to about 4.4 ml/l at a depth of 1200 m.

Stations 40~45 (Fig. 2, C).

The dissolved oxygen gradually increased from the surface to the depth of 75~100 m, and at a depth of 100 m the dissolved oxygen attained to 5.0 ml/l or more. Below a depth of 100 m the dissolved oxygen decreased with the depth and attained to the minimum value at 3.8 ml/l in a layer between 400 m and 500 m. Below the minimum layer, the dissolved oxygen increased again with the depth, and attained to the value 4.0~4.2 ml/l at a depth of 1200 m. The vertical distribution of the dissolved oxygen at above-mentioned stations can be grouped into three types. In the surface layer of all stations the content of dissolved oxygen was rich and there was no difference by region. In the northern area, a remarkable chemocline was recog-

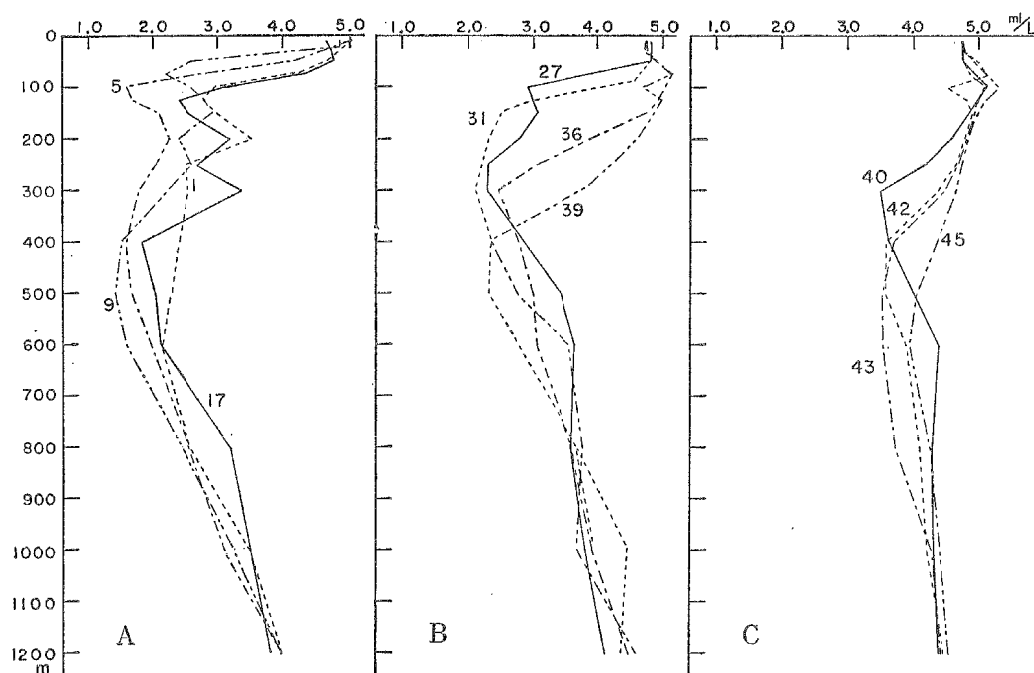


Fig. 2. Vertical distribution of dissolved oxygen.

nized, but with the shift of the stations to the southward the chemocline became indefinite. In the southern area (Fig. 2, C) the vertical change of dissolved oxygen became smaller than that in the northern area.

Phosphate-P.

The general trend of the vertical change in the concentration of phosphate-P showed that it attained to the minimum value at 0.2 $\mu\text{g-at/l}$ in the surface layer and attained to the maximum value from 1.7 to 2.0 $\mu\text{g-at/l}$ at a depth of 800 m or thereabout. Below a depth of 800 m phosphate-P decreased gradually with the depth. The patterns of the phosphate-P changed with the depth at various stations were classified

into three following groups:

Station 1 (Fig. 3, A).

In a surface layer the concentration of phosphate-P was about $0.3 \mu\text{g-at/l}$ and in a layer between 50 m and 100 m phosphate-P increased steeply with the depth and attained to $0.8 \mu\text{g-at/l}$. In a layer between 100 m and 200 m phosphate-P formed the inversion layer and decreased in about $0.2 \mu\text{g-at/l}$ with the depth. Below a layer of 200 m and thereabout phosphate-P gradually increased with the depth and attained to a maximum at $1.7 \mu\text{g-at/l}$ at a depth of 800 m.

Stations 5~33 (Fig. 3, B).

In a layer between the surface and a depth of 25 m the concentrations of

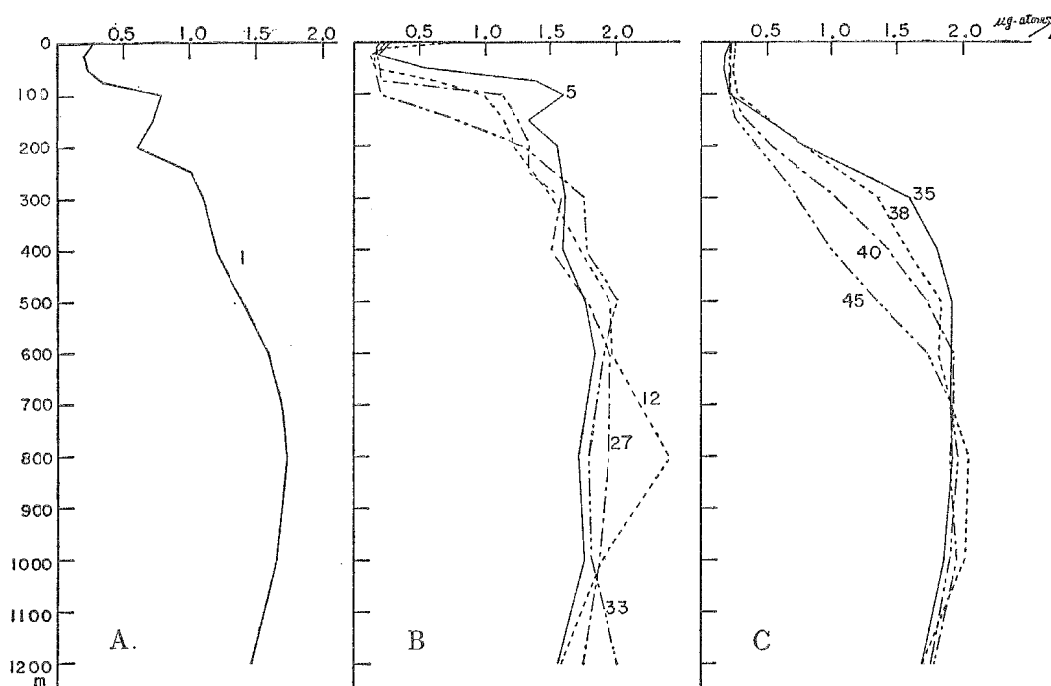


Fig. 3. Vertical distribution of phosphate-P.

phosphate-P were between 0.1 and $0.2 \mu\text{g-at/l}$, but between 25 m and 100 m there was a remarkable discontinuous layer. In a layer of a depth of 500 m or thereabout the concentrations of phosphate-P attained to the maximum at $1.8\sim 2.0 \mu\text{g-at/l}$. Especially, at a depth of 800 m at station 12 the concentrations of phosphate-P reached the highest record at $2.4 \mu\text{g-at/l}$.

Stations 35~45 (Fig. 3, C).

In a layer between the surface and a depth of 100 m the concentration of phosphate-P was nearly constant, but below a depth of 150 m it gradually increased and attained to the maximum at $1.8\sim 2.1 \mu\text{g-at/l}$ at and near a depth of 800 m.

The above-mentioned patterns of the vertical change in the concentration of phosphate-P were similar to those of dissolved oxygen and were classified into three

types by region. Up to now many workers reported that generally the concentration of phosphate-P in the Atlantic Ocean was lower than those in the Pacific and Indian Oceans, and the result of the authors' investigations showed the same fact.

Silicate-Si.

The patterns of the silicate-Si changed with the depth at various stations were classified into following three groups.

Stations 1~8, 10~24, 26 and 27 (Fig. 4, A).

In a layer between the surface and a depth of 25 m silicate-Si was 5~8 $\mu\text{g-at/l}$, but below a depth of 25 m silicate-Si increased gradually with the depth and reached the maximum value of 40~45 $\mu\text{g-at/l}$ at a depth of 1000 m.

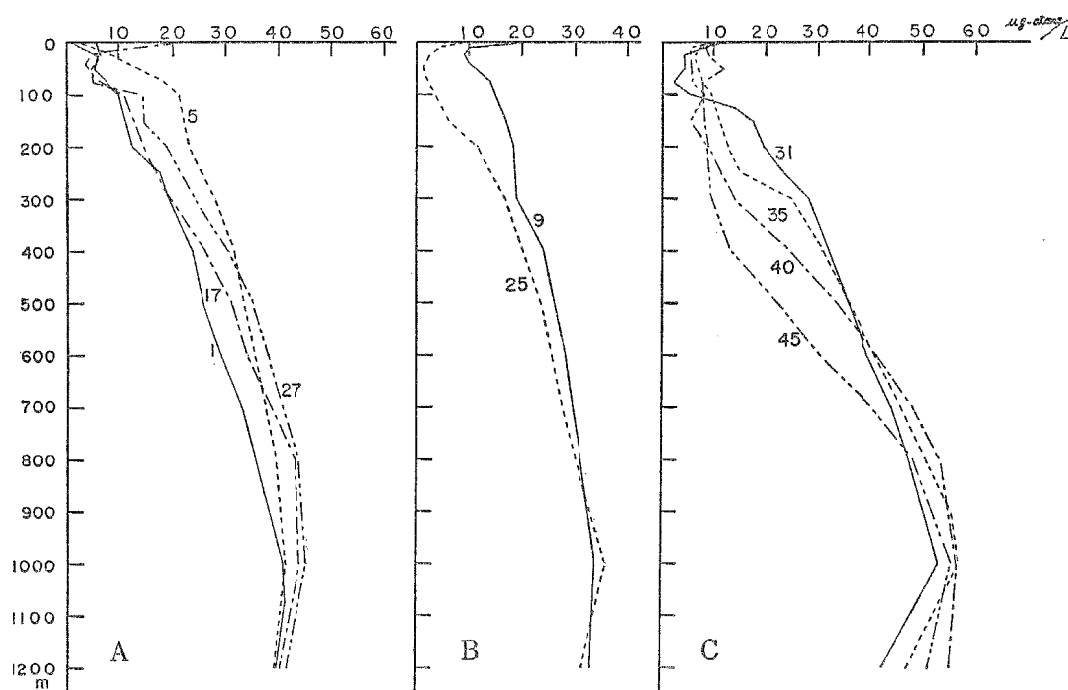


Fig. 4. Vertical distribution of silicate-Si.

Stations 9 and 25 (Fig. 4, B).

At these two stations the concentration of silicate-Si was characteristically lower than those at other stations, and attained to the maximum value at 35 $\mu\text{g-at/l}$ at a depth of about 1000 m.

Stations 31~45 (Fig. 4, C).

In a layer between the surface and a depth of 250 m, the concentration of silicate-Si was 10~15 $\mu\text{g-at/l}$ and nearly constant. Below a depth of 250 m the concentration of silicate-Si increased gradually and attained to the maximum value at 53~57 $\mu\text{g-at/l}$.

The concentration of silicate-Si in the intermediate layer showed the highest value among those of all groups.

Vertical distribution of chemical properties in the meridional cross section.

Dissolved oxygen (Fig. 5).

In the surface layer the chemocline of the dissolved oxygen content was delimited by the equivalent curve from 3.0 to 4.5 ml/l. This chemocline was shallow and remarkable in the northern part, but with the shift of the stations toward the south it sank and became indefinite. Moreover the oxygen chemocline topography corresponded well to the thermocline topography (temperature from 25°C to 18°C).

In the waters extended from the north to latitude 10°S or thereabout in the subsurface layer the oxygen was less than 2.5 ml/l. Especially the low oxygen layer (between 300 m and 700 m in depth) whose value was less than 2.0 ml/l was present up to latitude 5°N.

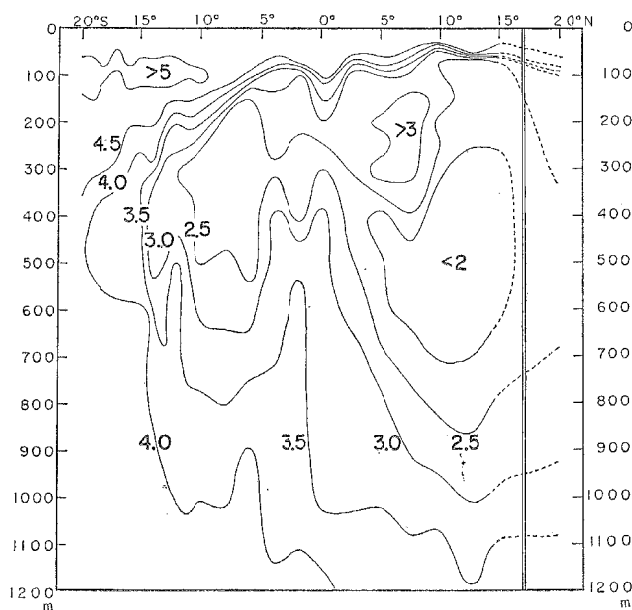


Fig. 5. Distribution of dissolved oxygen in the vertical cross section.

At and near the equator it was recognized that the intermediate water was rising. Generally speaking, in the southern part the content of dissolved oxygen was higher than that in the northern part. Especially the oxygen-rich water existed in the area south of latitude 14°S.

Phosphate-P (Fig. 6).

In the surface layer the isoquant topography at values of phosphate-P less than 1.0 $\mu\text{g-at/l}$ was similar to that of dissolved oxygen mentioned above, and well corresponded to the thermocline topography.

In the intermediate layer between 500 m and 1000 m, the phosphat-P content was more than 1.8 $\mu\text{g-at/l}$, and water masses having the values more than 2.0 $\mu\text{g-at/l}$ were

locally found in this layer. A layer between 400 m and 950 m in depth, centering around latitude 10°N , showed the content more than $2.0 \mu\text{g-at/l}$, and corresponded well to the above-mentioned low oxygen layer.

Moreover the distribution of a water mass surrounded by the isoquant of $1.8 \mu\text{g-at/l}$ coincided well with that of the Antarctic Intermediate Water.

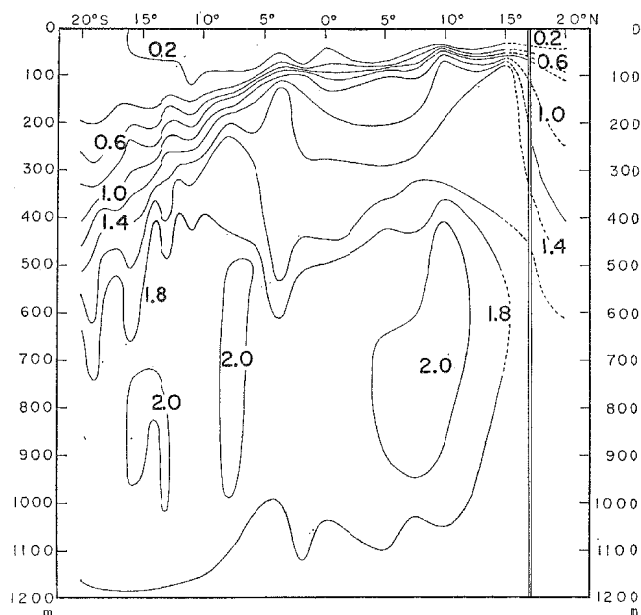


Fig. 6. Distribution of phosphate-P in the vertical cross section.

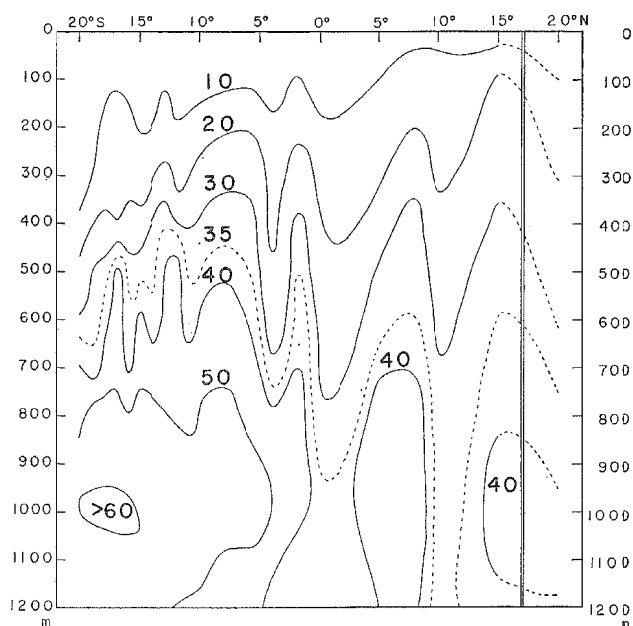


Fig. 7. Distribution of silicate-S in the vertical cross section.

Silicate-Si (Fig. 7).

The distribution of silicate-Si in the vertical cross section did not show any difference by region, but below a depth of 800 m the concentration of silicate-Si in the southern part was higher than that in the northern area. Especially a water mass having the concentration of $50 \mu\text{g-at/l}$ extended southward up to the equator, and also existed at latitude 5°S or thereabout. Moreover at latitude 5°S and latitude 13°S the convex or concave shape of silicate-Si isoquant was found in the subsurface layer.

Discussion and conclusion

From the above-mentioned analysis of the distributions of dissolved oxygen, the concentration of phosphate-P and silicate-Si, the authors attained to the following discussion and conclusion.

B. A. SKOPINTSEV and V. K. ZHAVORONKINA (1962) suggested that the distributions of dissolved oxygen and phosphate-P coincided well with water temperature and salinity distributions in this area. On the other hand, from the investigation in the equatorial region of the western Pacific Ocean, Y. NAGAYA (1959) estimated that the distributions of phosphate-P and dissolved oxygen show the similar patterns of rising and sinking, but do not coincide well with the patterns of the distributions of water temperature and salinity. He deduced the movements of the surface, intermediate and deep water masses from these patterns. From the results of our study, it was recognized that the distributions of dissolved oxygen and phosphate-P coincided with water temperature and salinity conditions, and therefore these distributions can be useful as an index for the estimation of currents and water masses.

Below the subsurface layer the layer showing the minimum oxygen content (between 100 m and 800 m in depth) existed from the Northern Hemisphere to latitude 10°S . Especially a layer with oxygen less than 2.0 ml/l (between 300 m and 100 m in depth) and having its center around 10°N was recognized. Moreover, it was found that this layer with low oxygen showed a good correspondence with a layer with the maximum concentration of phosphate-P being 100~200 m deeper than the former. This fact has been previously suggested by B. A. SKOPINTSEV (1962). But the mechanism of formation of this low oxygen layer is yet unknown.

Below a depth of 400 m, the water with $1.8 \mu\text{g-at/l}$ the concentration of phosphate-P extended from the south up to latitude 15°N , and corresponded to Antarctic Intermediate Water.

The concentration of silicate-Si in the southern part was higher than that in the northern area. Especially the water showing silicate-Si at $50 \mu\text{g-at/l}$ or over extend from the south to latitude 4°S and had its center around a depth of 1000 m.

References

- HIDAKA, K., 1955 : Kairyu, Iwanami Shoten, Tokyo. (in Japanese)
- NAGAYA, Y., 1959 : On the distributions of the nutrient salts in the equatorial region of the western Pacific. Jan.~Feb., 1958. *Hydrographic Bulletin* No. 59. (in Japanese with English summary)
- SINYUKCV, V. V., 1962 : Experimental use of an FEK-M photoelectric colorimeter for the determination of nitrites, silicates, and phosphates in sea water on the R/V "M. Lomonosov". *Soviet Oceanogr.*, **25**. (Translated and produced by scripta technica, inc. for the American Geophysical Union)
- SKOPINTSEV, B. A., & V. K. ZHAVORONKINA, 1962 : Results of determinations of dissolved oxygen in the waters of the subtropical and tropical regions of the north Atlantic in August~October 1959. *Ibid.*, **25**.
- SVERDRUP, H. U., JONSON, M. W. & R. H. FLEMING, 1952 : The oceans. 4th ed. Prentice-Hall, Inc., New York.
- TAWARA, S. & A. TSURUTA, 1966 : Water temperature relevant to distribution of zooplankton biomass in the tuna fishing ground in the eastern tropical Pacific. *This Jour.*, **14** (3). (in Japanese with English summary)
- TAWARA, S., TSURUTA, A. & H. IMANISHI, 1966 : Oceanographic conditions and zooplankton biomass in the tuna fishing ground in the central tropical Atlantic. *Ibid.*, **15** (3).