Vertical Distribution of Nutrients and DOC in Lake Waters near Syowa Station, Antractica

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昭和基地周辺の湖沼における栄養塩および DOC の鉛直分布

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要旨: 1977 年 1 月から 2 月にかけて昭和基地周辺の淡水湖および塩湖における栄養塩と溶存有機炭素 (DOC) を測定した．淡水湖の大池とスカーレン大池における栄養塩濃度は低く，表層から底層までほぼ一定であった．塩湖のぬるめ池とすりばち池は共に不完全循環湖であり，10 m 以深の無酸素層ではリン酸塩とアンモニア態窒素が著しく濃縮していた．これらの栄養塩はおそらく湖底堆積物から有機物の分解により供給されたものと推察される．

淡水および塩湖における DOC 濃度は，それぞれ 0.84–2.84 mg/*l*, および 1.63–1.86 mg/*l* の範囲を示し，最も高い値は舟底池の底層に見いだされた．塩湖において塩化物イオンと DOC 濃度に相関性が見られたことは起源水とされる海水が低温下において濃縮する過程で溶存有機炭素も蓄積することが示唆された．

Abstract: The vertical distribution of inorganic nutrients and DOC (dissolved organic carbon) was determined for two freshwater and three saline lakes near Syowa Station in January to February, 1977. In the freshwater lakes of Ô-ike and Skallen Ôike, the concentrations of nutrients were very low and their distributions were vertically homogeneous. Saline lakes of Nurume and Suribati, were typically meromictic and anoxic below 10 m depth. In the anoxic layers of these lakes, PO_4-P and NH_4-N were highly concentrated. These nutrients were probably originated from the decomposition of organic materials in the bottom sediments. The concentrations of nutrients in Lake Hunazoko, which is the most saline lake around Syowa Station, were considerably lower than those of Lakes Nurume and Suribati except for SiO_2-Si.

The concentration of DOC in the water of the freshwater and saline lakes ranged from 0.84 to 2.84 mg/*l* and from 1.63 to 186 mg/*l*, respectively. The highest value of DOC was found in the bottom of Lake Hunazoko. In the saline lakes studied, a significant correlation was found between chlorinity and DOC. This result may suggest that the high concentration of DOC in these lakes is attributable to concentration of sea water under freezing conditions.

1. Introduction

For the saline and freshwater lakes located in the Dry Vallyes region of south Victoria Land, many workers have extensively discussed the behavior and origin of chemical components including nutrients (ANGINO *et al.*, 1962; YAMAGATA *et al.*, 1967; PARKER *et al.*, 1973, 1975; HOEHN *et al.*, 1974, 1977; TORII *et al.*, 1975; FORTNER *et al.*, 1976; NAKAYA *et al.*, 1977; WEAND *et al.*, 1977; TORII and YAMAGATA, 1981;

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MATSUMOTO *et al.*, 1982). Besides, in the ice-free coastal region, such as the Prince Olav Coast, the biological and ecological investigations have been conducted by several investigators of the Japanese Antarctic Research Expedition (JARE). Although a number of studies on major chemical elements in lake waters of the Prince Olav Coast have been carried out, information on the behavior of nutrients is still limited (HIGANO, 1977; TOMINAGA, 1977; TOMINAGA and FUKUI, 1981; MURAYAMA *et al.*, 1981, 1984). In recent years, organic constituents have been studied by MATSUMOTO and HANYA (1977) and MATSUMOTO *et al.* (1984). In the present paper, we report the concentration of nutrients and DOC in the freshwater and saline lakes near Syowa Station.

2. Materials and Methods

2.1. Sampling

During a period from 14th of January to 9th of February in 1977, limnological observations were made on the five lakes, Lake Ô-ike in the West Ongul Island, Lake Skallen Ôike in the Skallen, Lake Nurume in the Langhovde and Lakes Suribati and Hunazoko in the Skarvsnes (Fig. 1). All water samples were taken from various depths at the center of the lakes using a Van Dorn sampler (2 *l*).

2.2. Analytical methods

Water temperature and pH were measured with a thermister and a pH meter with a glass electrode (Hitachi Horiba, Type D-5), respectively. Nutrients were determined as follows: PO_4-P (reduction with ascorbic acid), MURPHY and RILEY (1962); SiO_2-Si (molybdenum yellow), MÜLLIN and RILEY (1955); NO_2-N (Griess-Romijn), NISHIMURA *et al.* (1969); NO_3-N (cadmium reduction), WOOD *et al.* (1967); NH_4-N (indophenol), SOLÓRZANO (1969). Dissolved oxygen was determined by the WINKLER's method. These analyses were carried out at the field camp, and the colorimetric analyses were performed using a Hirama Model 4C Portable Photometer.

The water samples for DOC were frozen and brought to home laboratory in Japan. Analysis of DOC was made by the wet combustion method of MENZEL and VACCARO (1964). The precision of the determination was within the range of $\pm 5\%$.

3. Results and Discussion

3.1. Lake Ô-ike

Results on the inorganic nutrients and DOC in water of Lake Ô-ike are given in Table 1. The vertical changes in water temperature, pH, chlorinity, dissolved oxygen and SiO_2-Si were small. The average value of chlorinity was 107 mg/*l*. The lake waters may be slightly influenced by the wind-blown sea spray. Dissolved oxygen ranged from 9.30 to 9.41 m*l*/*l* which were slightly supersaturated. The average concentrations of PO_4-P, SiO_2-Si, NO_3-N, NO_2-N and NH_4-N were 0.07, 23, 0.1, 0.0_2 and 0.0 μg-at/*l*, respectively. The total inorganic nitrogen was very low and the maximum value was only 0.2 μg-at/*l* at 1 m depth. Low values of inorganic nitrogen and phosphate were the same one as those reported by MURAYAMA *et al.* (1981). The content of DOC was 1.02 mg/*l* in the surface water and the maximum value was 2.84 mg/*l* in

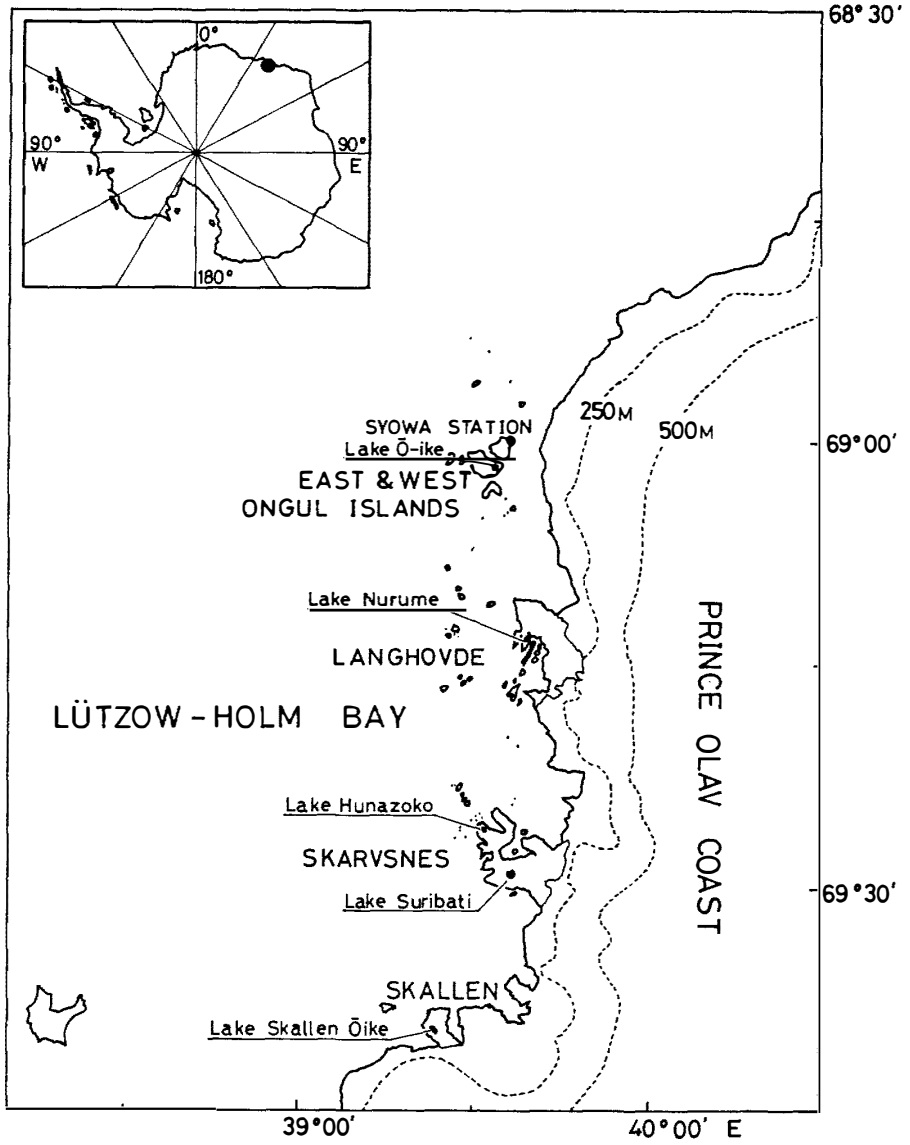

Fig. 1. Location of sampled lakes around Syowa Station.

Table 1. Inorganic nutrients and dissolved organic carbon in Lake Ô-ike on 15 January 1977.

Depth	Temp.	pH	Cl	Dis-solved Oxygen	SiO_2-Si	PO_4-P	NO_2-N	NO_3-N	NH_4-N	DOC
(m)	(°C)		(mg/*l*)	(m*l*/*l*)	(μg-at/*l*)					(mg/*l*)
0	5.7	6.8	104	9.36	23	0.02	0.0_3	<0.1	0	1.02
1	5.5	6.8	106	9.30	23	0.01	0.0_2	<0.1	0.1	2.84
2	5.3	6.8	108	9.33	23	0.08	0.0_1	<0.1	0	1.96
4	5.3	6.8	107	9.34	23	0.09	0.0_1	<0.1	0	0.97
6	5.3	6.8	108	9.35	23	0.08	0.0_1	<0.1	0	0.98
7.5	5.3	6.8	108	9.41	23	0.11	0.0_1	<0.1	0	0.97

Table 2. Inorganic nutrients and dissolved organic carbon in Lake Skallen Ôike on 8 February 1977.

Depth	Temp.	pH	Cl	Dissolved Oxygen	SiO_2-Si	PO_4-P	NO_2-N	NO_3-N	NH_4-N	DOC
(m)	(°C)		(mg/*l*)	(m*l*/*l*)			(μg-at/*l*)			(mg/*l*)
0	5.3	7.8	63	8.89	93	0.04	0.2$_1$	<0.1	0.3	1.12
1	5.3	7.8	63	8.67	91	0.04	0.0$_5$	<0.1	0.3	1.57
3	5.3	7.8	65	8.68	88	0.04	0.0$_2$	<0.1	0	1.40
6	5.3	7.8	63	8.69	89	0.04	0.0$_2$	<0.1	0	1.36
8	5.4	7.8	63	8.44	89	0.04	0.0$_5$	<0.1	0	0.84

the layer at 1 m depth. From 4 m to the bottom, the DOC contents were nearly constant.

3.2. Lake Skallen Ô-ike

The vertical distribution patterns of water temperature, pH, chlorinity, dissolved oxygen and SiO_2-Si were similar to those of Lake Ô-ike (Table 2). The average value of chlorinity was 63 mg/*l*. Dissolved oxygen ranged from 8.44 to 8.89 m*l*/*l* with a mean value of 8.67 m*l*/*l*. The average concentrations of PO_4-P, NO_3-N, NO_2-N and NH_4-N were 0.04, 0.1, 0.0$_7$ and 0.1 μg-at/*l*, respectively which were also very low as in the case of Lake Ô-ike. The concentration of SiO_2-Si (about 90 μg-at/*l*), however, was approximately four times higher than that of Lake Ô-ike. Concerning the high concentrations of SiO_2-Si, HIGANO (1977) suggested that the origin of SiO_2-Si is ascribed to the erosion of surrounding rocks. The obtained values of inorganic nutrients were somewhat similar to those reported by MURAYAMA *et al.* (1981, 1984). The content of DOC (1.12 mg/*l*) of the surface water was similar to that of Lake Ô-ike. The maximum value of DOC (1.57 mg/*l*) was found at 1 m depth, decreased with depth to the bottom and reached 0.84 mg/*l*. This value was the lowest among the five lakes studied. The DOC contents for the two freshwater lakes ranging from 0.84 to 2.84 mg/*l* were similar to those of thirty freshwater lakes in the Prince Olav Coast region (TOMINAGA, 1973).

3.3. Lake Nurume

Lake Nurume is a typical meromictic lake and has the maximum depth of 16 m (SANO *et al.*, 1977). WATANUKI (1977) pointed out that the lake water was originated from sea water. The maximum water temperature was found at 3 m depth (Table 3). The low water temperature at the surface layer (0–1 m) may be attributed to the meltwater. Chlorinity was 3.7 g/*l* in the surface layer, increasing with depth to the maximum value of 28.3 g/*l* at the bottom. Dissolved oxygen content increased gradually with depth from 8 m*l*/*l* in the surface layer to 11.36 m*l*/*l* at a depth of 9 m. The peak at 9 m depth, above the anoxic layer, may have been due to photosynthetic oxygen evolution by photosynthetic organisms. However, dissolved oxygen rapidly decreased and ultimately disappeared in the chemocline at a depth of 11 m. The PO_4-P and NH_4-N contents in the aerobic layer were considerably low or than those in the anoxic layer. Particularly, the NH_4-N content at the bottom was extremely high (2420

Table 3. Inorganic nutrients and dissolved organic carbon in Lake Nurume on 1 February 1977.

Depth	Temp.	pH	Cl	Dissolved Oxygen	SiO_2-Si	PO_4-P	NO_2-N	NO_3-N	NH_4-N	DOC
(m)	(°C)		(g/*l*)	(m*l*/*l*)			(μg-at/*l*)			(mg/*l*)
0	6.7	7.8	3.7	8.22	11	0.04	0.0_5	<0.1	0	1.70
1	6.8	7.5	3.9	8.04	11	0.04	0.0_2	<0.1	0	1.63
3	15.3	8.1	19.2	10.14	4	0.13	0.0_2	<0.1	0	8.2
5	10.9	8.1	19.3	10.50	7	0.17	0.0_2	<0.1	0	9.2
7	8.2	8.1	19.3	10.12	10	0.17	0.0_2	<0.1	0	9.0
9	8.8	8.2	20.0	11.36	30	1.13	0.0_7	<0.1	0.5	10.2
11	9.6	7.7	26.8	0	138	70	0.1_2	1.7	557	39.7
13	7.4	7.1	27.6	0	345	135	0.2_6	1.8	1790	15.7
15	6.9	7.1	28.3	0	426	156	0.2_2	1.7	2420	29.3

μg-at/*l*). This value is considerably higher than that of Lake Bonny (17.8 mg/*l*) in the Dry Valleys region (WEAND *et al.*, 1977) and that of Lake Suigetsu (23.7 mg/*l*), a meromictic lake in Japan (MATSUYAMA and SAIJO, 1973). However, the values of NH_4 are one order of magnitude higher than those of the results (159 μg-at/*l*, JARE-20) of MURAYAMA *et al.* (1981). Further detailed study on the analytical methods is required for the determination of NH_4 in the water of anoxic condition. The high concentrations of PO_4-P and NH_4-N suggest the decomposition of organic materials in the bottom sediments. The content of SiO_2-Si also increased with depth and reached 426 μg-at/*l* at the bottom which is the maximum value among the lakes studied near Syowa Station.

The DOC values ranging from 1.70 to 39.7 mg/*l* were remarkably different according to the sampling depths. The DOC value (1.70 mg/*l*) of the surface water was much lower than those of the underlying waters, suggesting the dilution with a melt-water coming from snow field and freezing-out phenomena in the winter season. The maximum value (39.7 mg/*l*) was found in the chemocline, which was the boundary of oxic and anoxic layers and a large accumulation of organic materials occurred there.

3.4. Lake Suribati

Lake Suribati is the largest of the five lakes studied and has the maximum depth of 31 m. The maximum water temperature of 8.2°C was found in the surface of the lake (Table 4). Chlorinity of the surface water was 30.7 g/*l* and it considerably increased with depth to 121 g/*l* at 10 m depth. Below this depth, the chlorinity was nearly constant. The chlorinity of 128 g/*l* at the bottom was approximately seven times higher than that of sea water. The maximum dissolved oxygen was 6.59 m*l*/*l* at a depth of 10 m and it decreased rapidly with depth down to 13 m. In the anoxic layer, the concentrations of PO_4-P (54.0–68.1 μg-at/*l*), SiO_2-Si (225–244 μg-at/*l*) and NH_4-N (458–575 μg-at/*l*) were considerably high and their vertical distributions were almost constant. The SiO_2-Si content in the aerobic layer was considerably high. These silicate may be attributable to erosion of rocks around the lake and elution from bottom sediment. NO_3-N was not detected in this lake and NO_2-N was detected only 0.0_5 μg-at/*l* in the aerobic layer. The composition of inorganic nitrogen was characterized

Table 4. Inorganic nutrients and dissolved organic carbon in Lake Suribati on 22 January 1977.

Depth	Temp.	pH	Cl	Dissolved Oxygen	SiO_2-Si	PO_4-P	NO_2-N	NO_3-N	NH_4-N	DOC
(m)	(°C)		(g/*l*)	(ml/*l*)			(μg-at/*l*)			(mg/*l*)
0	8.2	7.8	30.7	5.92	105	0.05	0.0_5	0	0	20.6
1	8.1	7.8	51.1	5.40	129	0.05	0.0_2	0	0	29.5
4	5.3	7.6	96.5	5.59	196	0.41	0.0_2	0	1.7	82.5
7	1.8	7.4	99.3	5.47	194	0.40	0.0_6	0	1.7	85.5
10	6.4	—	121	6.59	239	11.1	0.0_3	0	32.5	127
13	5.8	7.1	126	0	244	54.0	—	0	458	131
16	5.3	7.2	127	0	233	56.7	0	0	458	106
19	4.2	7.2	127	0	235	57.3	0	0	530	107
22	2.8	7.1	127	0	232	59.3	0	0	527	122
25	2.0	7.1	126	0	237	68.1	0	0	566	122
28	1.7	7.1	128	0	230	67.5	0	0	550	128
29	1.7	7.1	128	0	225	66.7	0	0	575	125

by the absence of NO_3-N and high abundance of NH_4-N throughout the water column.

The DOC value increased from the surface (20.6 mg/*l*) to a depth of 13 m (131 mg/*l*), but it decreased to 19 m depth. Below this depth, the DOC values were nearly constant. The DOC concentrations in the monimolimnions were much higher than that of mixolimnions of Lakes Nurume and Suribati. These results showed that a large accumulation of organic materials occurred in the anoxic layers of both the lakes.

3.5. Lake Hunazoko

Water temperature of the lake decreased significantly from the surface (11.5°C) to the bottom (−13.0°C, Table 5). The thermal stratification was clearly demonstrated in the lake water, so the stagnation of water was found in this summer season. In the winter season, however, HIRABAYASHI and OSSAKA (1977) observed a minimum water temperature of −18.3°C through the entire water column, suggesting complete water circulation. The surface chlorinity was 112 g/*l* which was slightly affected by meltwater of snow. The maximum chlorinity of 158 g/*l* was found at the bottom. It was approximately eight times higher than that of sea water. Dissolved oxygen contents in the surface and at a depth of 7 m were 2.19 and 2.17 ml/*l*, respectively.

Table 5. Inorganic nutrients and dissolved organic carbon in Lake Hunazoko on 24 January 1977.

Depth	Temp.	pH	Cl	Dissolved Oxygen	SiO_2-Si	PO_4-P	NO_2-N	NO_3-N	NH_4-N	DOC
(m)	(°C)		(g/*l*)	(ml/*l*)			(μg-at/*l*)			(mg/*l*)
0	11.5	7.8	112	2.19	155	0.25	0.1_6	1.9	1.7	103
1	10.6	7.7	118	—	156	0.33	0.2_7	1.5	5.7	121
3	5.6	7.5	157	2.57	213	0.32	0.4_5	1.0	4.8	162
4	− 9.5	7.5	157	2.28	220	0.33	0.4_9	1.3	5.7	178
7	−13.0	7.4	158	2.17	227	0.45	0.4_9	1.4	6.0	186

Although the stagnation was found in the summer season, the vertical distribution of nutrients was nearly constant except for the surface layer. The concentrations of SiO_2-Si, PO_4-P, NO_3-N, NO_2-N and NH_4-N in the lake were 155–227, 0.25–0.45, 1.0–1.9, 0.1_6–0.4_9 and 1.7–6.0 μg-at/l, respectively. The high concentration of SiO_2-Si may be considered to be due to the erosion of surrounding rocks. The composition of inorganic nitrogen was characterized by the presence of NH_4-N, NO_3-N and NO_2-N at all the depths. Extremely high DOC values (103–186 mg/l) were observed in the water column. The highest DOC of 186 mg/l for the bottom water was also the highest value among the five lakes.

Although there is a considerable difference in the chlorinity and DOC concentration among the saline lakes, a significant correlation was found between them. This result may suggest that the high levels of DOC in these saline lakes are attributable to concentration of sea water under freezing conditions.

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