

Nutrient Matters in Saline Lakes of McMurdo Oasis in the 1976–77 Summer Season

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1976–77年夏期における南極マクマードオアシスの塩湖の栄養塩類

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要旨: 1976–77年のフィールドシーズンに南極のロス島、ロイド岬のホーム湖、ドライバレー地域のライト谷のバンダ湖、テイラー谷のボニー湖およびピアス谷のジョイス湖の栄養塩類の研究を行った。その結果ホーム湖の $\text{PO}_4\text{-P}$ 濃度は非常に高く、湖の周辺のアデリーペンギンおよび盗賊カモメの排泄物の影響が著しいことが推察された。バンダ湖およびボニー湖における栄養塩類の鉛直分布のパターンは、一般に従来の報告と同様でかなり安定していることが確認された。さらに今回初めて調査したジョイス湖にも高濃度の $\text{NO}_3\text{-N}$ および $\text{NH}_4\text{-N}$ が検出され、この地域の湖の窒素化合物の濃度が一般に高いという特徴と矛盾しないことが判明した。しかしながら、ボニー湖における $\text{NH}_4\text{-N}$ 濃度は、従来の報告と著しく異なり、高塩分濃度における $\text{PO}_4\text{-P}$ の測定とともに、分析方法の検討がさらに望まれる。

Abstract: In the 1976–77 austral summer, the distribution of nutrient matters was studied for the waters of Home Lake at Cape Royds of Ross Island, Lake Vanda in the Wright Valley, Lake Bonney in the Taylor Valley and Lake Joyce in the Pearse Valley in the dry valleys of Victoria Land in the Antarctic. High concentration of $\text{PO}_4\text{-P}$ was found in Home Lake, reflecting presumably the influence of the excretions of the Adélie penguin and the skua around the lake. In general, the vertical distribution pattern of nutrient matters in Lakes Vanda and Bonney was similar to those revealed by the previous studies, although the contents of $\text{NH}_4\text{-N}$ in the lakes were considerably different from those of the previous works. In addition, high contents of inorganic nitrogen components ($\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$) were found in Lake Joyce. This result is consistent with that inorganic nitrogen components in the lakes of the dry valleys are generally abundant. These nitrogen components were thought to be supplied by glacial meltwater and from lake sediment. However, the studies on the analytical methods should further be required for the determination of $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ in highly saline waters.

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1. Introduction

The dry valleys area is the largest oasis in the Antarctic, in which are found a number of lakes and ponds including saline ones. Since the pioneering investigations of the dry valleys lakes by ARMITAGE and HOUSE (1962), limnological studies have been carried out extensively by many scientists. In particular, TORII and his co-workers (1975, 1981) have studied the distribution of chemical components including nutrient matters in the lakes of the dry valleys and discussed their origin. The study on the nutrient matters in McMurdo Oasis has been conducted mainly for Lake Vanda in the Wright Valley and Lakes Bonney and Fryxell in the Taylor Valley. The east lobe of Lake Bonney, especially, has been investigated intensively for limnological aspects including seasonal variation of nutrient matters by the research group of the Virginia Polytechnic Institute and the State University (FORTNER *et al.*, 1976; HOEHN *et al.*, 1977; WEAND *et al.*, 1977). It is generally known that inorganic nitrogen components ($\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and/or $\text{NH}_4\text{-N}$) are abundant in these lake waters (TORII *et al.*, 1975; FORTNER *et al.*, 1976; NAKAYA *et al.*, 1977; HOEHN *et al.*, 1977; WEAND *et al.*, 1977; TORII and YAMAGATA, 1981). However, no one has studied nutrient matters in Home Lake of Ross Island and Lake Joyce in the Pearse Valley of McMurdo Oasis. Here we report principally the vertical distribution of nutrient matters in Home Lake and Lakes Joyce, Vanda and Bonney.

2. Materials and Methods

2.1. Sampling

In December 1976, after drilling into lake ice with a Sypre Ice Auger, water samples were taken by a Kitahara-type water sampler (1 l) with a stainless steel wire. Water samples were collected from Home Lake at Cape Royds of Ross Island, Lake Vanda and the mouth of the Onyx River in the Wright Valley, the west and east lobes of Lake Bonney in the Taylor Valley and Lake Joyce in the Pearse Valley (Fig. 1).

2.2. Analytical methods

Water temperature, electric conductivity and pH values were measured by means of a thermister-thermometer (Tama Kagaku Co. Ltd.), an M-3M type conductometer (Toa Dempa Co. Ltd.) and a Toshiba-Beckman Model N2 pH-meter, respectively. To prevent the interferences from coexisting materials in water sample, and on account of the difficulty in purchasing α -naphthylamine for Griess-Romijin reagent, the $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ contents were determined by the following analytical methods, which were different from those of the previous methods (TORII *et al.*, 1975; NAKAYA *et al.*, 1977). $\text{NO}_2\text{-N}$ (sulfanilamide-N-(1-naphthyl)ethylenediamine), $\text{NO}_3\text{-N}$ ($\text{NO}_2\text{-N}$

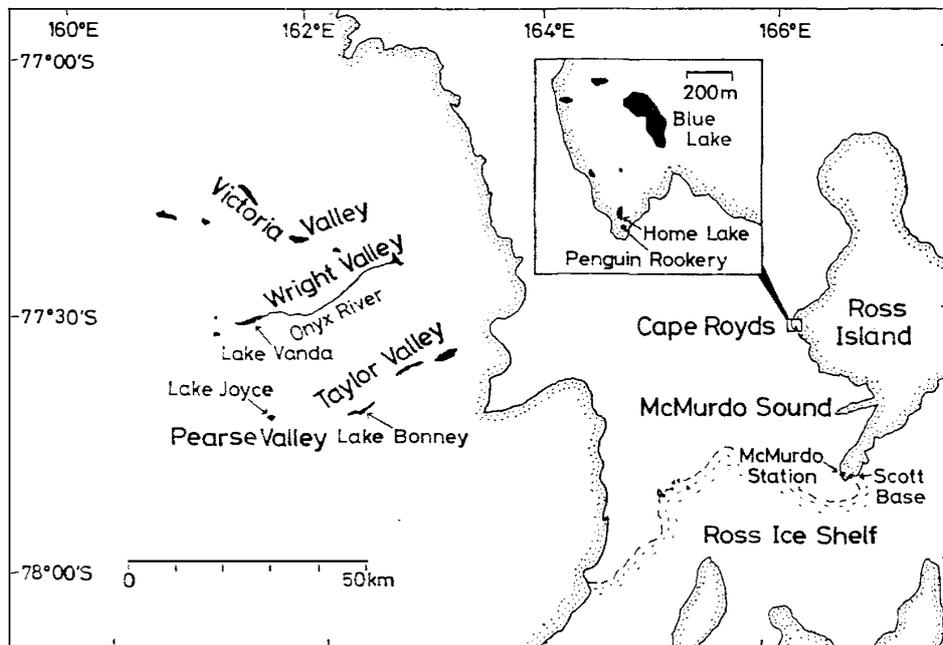


Fig. 1. Sampling locations in McMurdo Oasis in the Antarctic. ●: Lake or pond.

method after cadmium column reduction) and $\text{NH}_4\text{-N}$ (indophenol) were determined by the methods which were principally based on the Manual of Oceanographic Observation (JAPAN METEOROLOGICAL AGENCY, 1970) and A Practical Handbook of Seawater Analysis (STRICKLAND and PARSONS, 1972) with some modification. Alkalinity (BCG, pH 4.3), dissolved oxygen (Winkler's chemical method), $\text{SiO}_2\text{-Si}$ (molybdenum yellow method) and $\text{PO}_4\text{-P}$ (reduction with ascorbic acid) values were determined by the similar procedures to the previous works. When hydrogen sulfide is present in the water sample, mercuric chloride solution was added to the sample to prevent the interference due to sulfide ions (NISHIMURA *et al.*, 1969). Colorimetric analysis was performed with a Hirama Model 4C Portable Photometer.

These analyses were carried out on the spot within 24 hours after sampling except for $\text{NO}_3\text{-N}$. The analysis of $\text{NO}_3\text{-N}$ was made at the Eklund Biological Center of McMurdo Station.

3. Results and Discussion

3.1. Water temperature

The vertical profile of water temperatures in Lake Vanda and the west and east lobes of Lake Bonney was similar to those of the previous studies (TORII *et al.*, 1975; HOEHN *et al.*, 1977; Fig. 2). In Lake Joyce of the Pearse Valley, the vertical variation of water temperatures was very small (0–1°C), suggesting that the stratification of lake

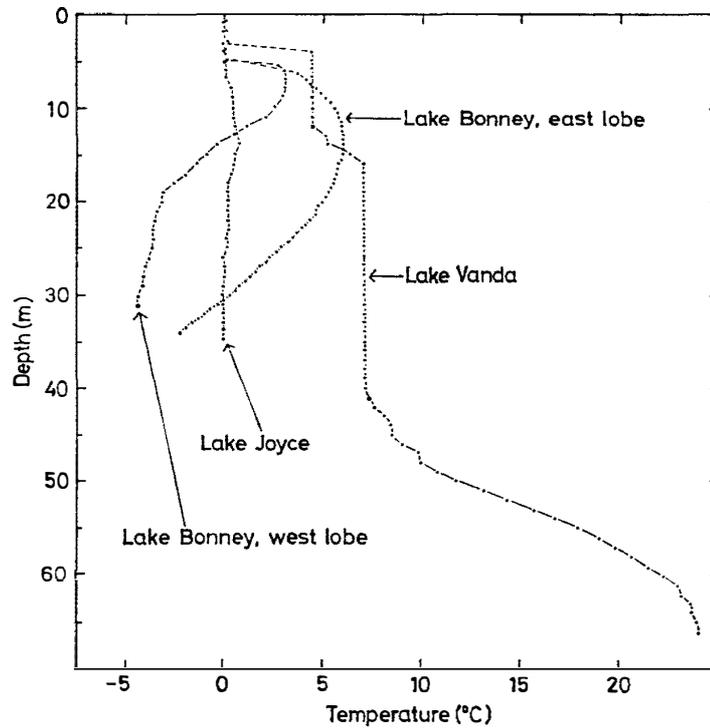


Fig. 2. Vertical profile of water temperatures in Antarctic saline lakes.

water is labile. The temperatures of surface waters of Home Lake and the mouth of the Onyx River were 1.0 and 1.9°C, respectively.

3.2. Home Lake

According to ARMITAGE and HOUSE (1962), electric conductivity, pH and chlorinity in Home Lake are 8200 $\mu\text{mho/cm}$, 9.0 and 1675 mg/l , respectively. In the present study, electric conductivity and pH were 1.4×10^4 $\mu\text{mho/cm}$ at 18°C and 5.60, respectively (Table 1). Home Lake is small (length, *ca.* 100 m; width, 50 m), and there is a rookery of the Adélie penguin around the lake. Furthermore, a number of skua are also found around the lake. Thus the water level and the chemical composition of the lake water may vary considerably with seasons. Although the total organic carbon content of the lake water is extremely high (110 mgC/l , MATSUMOTO *et al.*, 1979), dissolved oxygen was supersaturated (11.1 ml/l). $\text{NO}_2\text{-N}$, $\text{NO}_3\text{-N}$, $\text{NH}_4\text{-N}$, $\text{SiO}_2\text{-Si}$

Table 1. Nutrient matters in Home Lake (sampling date: December 8, 1976).

Depth (m)	Electric conductivity at 18°C ($\mu\text{mho/cm}$)	pH	Dissolved O_2 (ml/l)	Alkalinity (meq/l)	$\text{NO}_2\text{-N}$ ($\mu\text{g-at/l}$)	$\text{NO}_3\text{-N}$ ($\mu\text{g-at/l}$)	$\text{NH}_4\text{-N}$ ($\mu\text{g-at/l}$)	$\text{SiO}_2\text{-Si}$ ($\mu\text{g-at/l}$)	$\text{PO}_4\text{-P}$ ($\mu\text{g-at/l}$)
Surface	1.4×10^4	5.60	11.1	2.06	3.1	5.6	36	240	190

and PO₄-P were all detected in various concentrations. Especially, the content of PO₄-P is remarkably high, which must reflect the influence of the excretions of the Adélie penguin and the skua around the lake.

3.3. Lake Vanda

The analytical results for Lake Vanda were summarized in Table 2. Electric conductivity increased with depth and attained the value more than 1.0×10^5 $\mu\text{mho/cm}$ in the bottom layer (65.9 m). Low pH value (5.46) was obtained in the bottom layer as in the case of the previous results (TORII *et al.*, 1975). Dissolved oxygen was supersaturated from the surface to a depth of 55.4 m, but decreased abruptly and reached zero in the bottom layer. Alkalinity increased with depth and reached a maximum value of 5.13 meq/l in the bottom layer. NO₂-N and NO₃-N values increased from the surface to a depth of 55.4 m, but then decreased to the bottom layer. However, the maximum value of NO₃-N was more than twice that of the previous studies (TORII *et al.*, 1975; NAKAYA *et al.*, 1977); it may depend on the sampling seasons, because the NO₃-N content at a depth of 25 m of the east lobe of Lake Bonney in the 1974–75 austral summer changed considerably in the range from 2050 to 3450 $\mu\text{g/l}$ (WEAND *et al.*, 1977).

The contents of NH₄-N for the depths of 55.4 and 60.4 m were 56 and 110 $\mu\text{g-at/l}$, respectively, one order of magnitude greater than those of the previous ones. At least two reasons are considered: First, the difference of analytical methods, since the indophenol method was applied to this study, whereas the method of RICHARDS and KLETSCH (1964) was used in the previous works. However, the difference of these analytical methods was not of importance, because the comparison of these methods

Table 2. Nutrient matters in Onyx River and Lake Vanda*
(sampling date: December 13–14, 1976).

Sample	Depth (m)	Electric conductivity at 18°C ($\mu\text{mho/cm}$)	pH	Dissolved O ₂ (ml/l)	Alkalinity (meq/l)	NO ₂ -N ($\mu\text{g-at/l}$)	NO ₃ -N ($\mu\text{g-at/l}$)	NH ₄ -N ($\mu\text{g-at/l}$)	SiO ₂ -Si ($\mu\text{g-at/l}$)	PO ₄ -P ($\mu\text{g-at/l}$)
Onyx River	Surface	5.5×10^2	6.81	10.9	0.08	0.41	8.9	0	60	0.3
Lake Vanda*	5.4	8.2×10^2	7.18	13.5	0.74	0.06	6.2	1	140	0.1
	10.4	8.8×10^2	7.81	14.9	0.74	0.07	5.6	1	140	0.1
	30.4	1.3×10^3	7.80	17.9	1.04	0.04	5.9	0	240	0.0
	50.4	9.8×10^3	6.96	13.1	1.44	0.07	56	0	270	0.0
	55.4	4.5×10^4	6.21	16.9	2.01	1.6	220	56	500	?
	60.4	7.3×10^4	5.60	0.1	3.36	0.23	2.9	110	630	?
	65.9	$>1.0 \times 10^5$	5.46	0.0	5.13	?	?	?	?	?

* Bottom, 66.4 m.

for the determination of $\text{NH}_4\text{-N}$ in waters from the lower layer of Lake Vanda showed similar results (NAKAYA *et al.*, unpublished results). The second reason, therefore, is that the changes of the $\text{NH}_4\text{-N}$ content are much likely due to seasonal variation of lake water, because the content of $\text{NH}_4\text{-N}$ at a depth of 25 m in the east lobe of Lake Bonney varied remarkably from 3020 to 17800 $\mu\text{g/l}$ in the 1974–75 season (WEAND *et al.*, 1977). Further detailed studies including the seasonal variations of nutrient matters should be important.

The $\text{SiO}_2\text{-Si}$ values increased from the surface to the bottom layer, but the values at depths deeper than 50.4 m were about a half of the previous works. $\text{PO}_4\text{-P}$ was found at the depths of 5.4 and 10.4 m in small amounts. However, the $\text{PO}_4\text{-P}$ values could not be determined for the deeper layers (≥ 55.4 m), because precipitation occurred on the addition of the reagent solution. In general, the vertical distribution pattern of nutrient matters was similar to those of the previous works (TORII *et al.*, 1975; NAKAYA *et al.*, 1977).

3.4. Lake Bonney

In the west lobe of Lake Bonney, the vertical distribution patterns of electric conductivity, pH, dissolved oxygen, alkalinity and $\text{PO}_4\text{-P}$ values were similar to those of the previous studies as in the case of Lake Vanda (TORII *et al.*, 1975; NAKAYA *et al.*, 1977; Table 3). That is, electric conductivity increased with depth and reached the value more than 1.0×10^5 $\mu\text{mho/cm}$ in the bottom layer (30.2 m). In principle, pH decreased with depth. Dissolved oxygen was supersaturated at the depths of 5.4 and 8.4 m, but decreased rapidly to zero in the bottom layer. Alkalinity increased with depth, but the values below a depth of 13.4 m were about a half of the previous works. Although $\text{PO}_4\text{-P}$ was not detected above a depth of 13.4 m, it was found in the deeper layer and attained a maximum value of 0.7 $\mu\text{g-at/l}$ in the bottom layer.

The $\text{NO}_2\text{-N}$ value showed two maxima at the depths of 5.4 and 18.4 m (Table 3).

Table 3. Nutrient matters in the west lobe of Lake Bonney*
(sampling date: December 21, 1976).

Depth (m)	Electric conductivity at 18°C ($\mu\text{mho/cm}$)	pH	Dissolved O_2 (ml/l)	Alkalinity (meq/l)	$\text{NO}_2\text{-N}$ ($\mu\text{g-at/l}$)	$\text{NO}_3\text{-N}$ ($\mu\text{g-at/l}$)	$\text{NH}_4\text{-N}$ ($\mu\text{g-at/l}$)	$\text{SiO}_2\text{-Si}$ ($\mu\text{g-at/l}$)	$\text{PO}_4\text{-P}$ ($\mu\text{g-at/l}$)
5.4	1.8×10^3	7.65	18.3	1.28	0.31	13.5	0	47	0.0
8.4	7.1×10^3	7.96	32.5	3.15	0.15	12.5	0	67	0.0
13.4	7.3×10^4	6.22	1.9	42.0	0.04	24.4	190	250	0.0
18.4	8.8×10^4	6.02	0.7	42.2	0.37	12.7	130	240	0.1
25.4	$> 1.0 \times 10^5$	5.90	0.0	49.3	0.01	0.0	48	190	0.3
30.2	$> 1.0 \times 10^5$	5.88	0.0	51.6	0.01	0.0	29	180	0.7

* Bottom, 30.6 m.

According to the previous works (TORII *et al.*, 1975; NAKAYA *et al.*, 1977), the NO₂-N content at the depths between 10 and 26 m is constant (0.5 µg-at/l) and the values at the depths above or below are lower than this constant value. Besides, the NO₃-N results show a maximum value of 24.4 µg-at/l at a depth of 13.4 m. The NH₄-N content increased from the surface to a depth of 13.4 m (190 µg-at/l), but then decreased to the bottom layer. These values are more than one order of magnitude greater than those of the previous studies (TORII *et al.*, 1975; NAKAYA *et al.*, 1977) as in the case of Lake Vanda. The SiO₂-Si values increased from the surface to a depth of 13.4 m (250 µg-at/l), but then gradually decreased toward the bottom, whereas the previous results of SiO₂-Si were almost constant between the depths of 10 and 29.5 m (191–203 µg-at/l). These differences may be attributed to the contribution of meltwater from the Taylor Glacier and other alpine glaciers and microbial activity in the lake.

In the east lobe of Lake Bonney, electric conductivity increased with depth (Table 4). The pH values ranged from 6.05 to 8.34. Dissolved oxygen at the depths from 5.4 to 10.4 m showed supersaturation (23.3–28.0 ml/l), but then it decreased to the bottom layer (33.4 m), although it still remained in small amount. Alkalinity increased from the surface to a depth of 19.4 m, but then decreased to the bottom layer. The NO₂-N and NO₃-N values increased from the surface to the depths of 25–30 m (40 and 210 µg-at/l, respectively), but decreased also slightly in the bottom layer. These values are comparable to those of the results (420–624 and 2050–3450 µg/l, respectively) of WEAND *et al.* (1977), but somewhat different from those of the reports (13.2 and 459 µg-at/l, respectively) of TORII *et al.* (1975) and NAKAYA *et al.* (1977). However, their vertical profiles are generally similar to those of the previous results (TORII *et al.*, 1975; NAKAYA *et al.*, 1977; WEAND *et al.*, 1977).

The NH₄-N contents increased with depth and reached a maximum value of 58

Table 4. Nutrient matters in the east lobe of Lake Bonney*
(sampling date: December 24, 1976).

Depth (m)	Electric conductivity at 18°C (µmho/cm)	pH	Dissolved O ₂ (ml/l)	Alkalinity (meq/l)	NO ₂ -N (µg-at/l)	NO ₃ -N (µg-at/l)	NH ₄ -N (µg-at/l)	SiO ₂ -Si (µg-at/l)	PO ₄ -P (µg-at/l)
5.4	1.9×10 ³	8.34	23.3	1.64	0.25	16	2	61	0.0
10.4	2.0×10 ⁴	6.78	28.0	5.96	0.25	25	4	78	0.0
15.4	7.1×10 ⁴	6.58	9.4	13.1	1.6	80	38	220	0.0
19.4	>1.0×10 ⁵	6.05	0.4	15.6	9.0	170	55	37	0.0
25.4	>1.0×10 ⁵	6.70	0.8	9.18	40	210	58	12	0.0
30.4	>1.0×10 ⁵	6.70	2.9	8.94	39	210	47	8.5	0.0
33.4	>1.0×10 ⁵	6.77	4.1	6.40	31	190	46	6.5	0.0

* Bottom, 33.8 m.

$\mu\text{g-at/l}$ at a depth of 25.4 m, but decreased slightly to the bottom layer. Although these values are considerably higher than those of the results (2.2–26.5 $\mu\text{g-at/l}$) of TORII *et al.* (1975) and NAKAYA *et al.* (1977), they are one order of magnitude lower than those of the results (3020–17800 $\mu\text{g/l}$) of WEAND *et al.* (1977). For the determination of $\text{NH}_4\text{-N}$, FORTNER *et al.* (1976), HOEHN *et al.* (1977) and WEAND *et al.* (1977) used the similar analytical reagents to ours, but they carried out simultaneously standard addition method to compensate the effects of complex chemical matrix on color development. If so, it is probable that our $\text{NH}_4\text{-N}$ results are underestimated for waters from the east lobe of Lake Bonney. Further detailed study on the analytical methods should be required for the determination of $\text{NH}_4\text{-N}$ in highly saline waters.

No $\text{PO}_4\text{-P}$ ($<0.1 \mu\text{g-at/l}$) was found at all the depths of the east lobe of Lake Bonney in this study. According to FORTNER *et al.* (1976), HOEHN *et al.* (1977) and WEAND *et al.* (1977), however, considerable amounts of $\text{PO}_4\text{-P}$ ($<0.1\text{--}205 \mu\text{g/l}$) are found in the east lobe of Lake Bonney. The various contents of $\text{PO}_4\text{-P}$ are presumably ascribed to the seasonal variation of the lake water.

In general, the vertical profiles of nutrient matters in the west and east lobes of Lake Bonney were similar to those of the previous results (TORII *et al.*, 1975; NAKAYA *et al.*, 1977; WEAND *et al.*, 1977), although the $\text{NH}_4\text{-N}$ contents were remarkably different from each other.

3.5. Lake Joyce

Electric conductivity increased from the surface to a depth of 20.4 m, but was almost constant to the bottom layer, suggesting that the stratification of lake water is labile as indicated also by the water temperature profile (Fig. 2, Table 5). High pH values of the depths of 5.4 (8.99) and 13.4 m (9.00) with the supersaturation of dissolved oxygen suggest that the photosynthetic activity in the upper layer of the lake is considerably high. But no dissolved oxygen was found in the lower layer (30.4 m). Alkalinity and $\text{SiO}_2\text{-Si}$ values increased with depth and attained the maximum values

Table 5. Nutrient matters in Lake Joyce* (sampling date: December 18, 1976).

Depth (m)	Electric conductivity at 18°C ($\mu\text{mho/cm}$)	pH	Dissolved O_2 (ml/l)	Alkalinity (meq/l)	$\text{NO}_2\text{-N}$ ($\mu\text{g-at/l}$)	$\text{NO}_3\text{-N}$ ($\mu\text{g-at/l}$)	$\text{NH}_4\text{-N}$ ($\mu\text{g-at/l}$)	$\text{SiO}_2\text{-Si}$ ($\mu\text{g-at/l}$)	$\text{PO}_4\text{-P}$ ($\mu\text{g-at/l}$)
5.4	1.4×10^2	8.99	18.2	0.25	0.32	570	0	39	0.1
13.4	1.5×10^3	9.00	32.8	1.10	0.55	100	0	210	0.1
20.4	3.9×10^3	6.95	3.2	5.30	0.05	14	1.1	450	0.0
25.4	3.9×10^3	6.97	0.4	5.58	0.05	1.4	7.4	490	0.2
30.4	4.0×10^3	6.59	0.0	6.17	0.00	0.8	66	500	3.2

* Bottom, 34.8 m.

of 6.17 meq/l and 500 $\mu\text{g-at/l}$, respectively in the lower layer. The maximum $\text{NO}_2\text{-N}$ content (0.55 $\mu\text{g-at/l}$) was obtained at a depth of 13.4 m and then decreased to the lower layer, although these values were generally low. The $\text{NO}_3\text{-N}$ content of the surface water (570 $\mu\text{g-at/l}$) was extremely high, but decreased rapidly with depth and reached only 0.8 $\mu\text{g-at/l}$ at a depth of 30.4 m. On the other hand, the $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ values increased with depth and attained the maximum values of 66 and 3.2 $\mu\text{g-at/l}$, respectively, at a depth of 30.4 m. These results imply that the reduction of $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ and the decomposition of organic matter have occurred in the lake bottom. These inorganic nitrogen components may be derived from glacial meltwaters and from lake sediments (TORII *et al.*, 1975; NAKAYA *et al.*, 1977; HOEHN *et al.*, 1977).

4. Conclusions

The $\text{PO}_4\text{-P}$ content of Home Lake of Ross Island is extremely high. In general, the vertical profile of nutrient matters in Lakes Vanda and Bonney is similar to those of the previous studies, although the $\text{NH}_4\text{-N}$ content is considerably different from the previous works. The $\text{NO}_3\text{-N}$ and $\text{NH}_4\text{-N}$ contents in Lake Joyce showed high values, which is consistent with that inorganic nitrogen components in the dry valleys lakes are generally abundant. These nitrogen components can be supplied through meltwaters from glacier and also derived from lake sediments. On the other hand, it was indicated that no marked difference of analytical results was found in spite of the changes of analytical methods. However, detailed studies of the analytical methods for $\text{NH}_4\text{-N}$ and $\text{PO}_4\text{-P}$ in highly saline waters are desired strongly.

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