

# Mass Balance of Salts in Lake Vanda

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バンダ湖における塩収支について

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**要旨：**南極ライト谷から採取された堆積物コア，DVDP 4A と DVDP 14 について，分別溶解法を用いた分析を行った。そして，堆積物の各構成鉱物への化学元素の分配を明らかにした。それらの結果を用いて，バンダ湖における塩収支を計算し，バンダ湖の年齢を約7000年と見積もることができた。

**Abstract:** Two sediment cores, DVDP 4A and DVDP 14 taken from the Wright Valley, Antarctica, were analyzed by using a selective chemical leaching technique. The partitioning of chemical elements into each mineral species in the sediment was clarified. By using the results, the mass balance of salts in Lake Vanda was calculated and the age of Lake Vanda was estimated to be about 7000 years.

## 1. Introduction

Lake Vanda in the Wright Valley of Antarctica is well known as the lake in which salinity is stratified and the temperature of the water increases toward the bottom. The salinity of the bottom water reaches three times larger than that of seawater. The various origins of salts in Lake Vanda have been proposed by many researchers; MASUDA *et al.* (1982) insisted the aerosol origin based on the analysis of heavy metals, and JONES and FAURE (1967) proposed that the salts in Lake Vanda were derived through chemical weathering of rocks judging from the isotopic composition of strontium.

The present authors reported already about the salt origin in the Don Juan basin, the south fork of the Wright Valley and the western area of Lake Vanda (TOMIYAMA *et al.*, 1983). The water in Lake Vanda is supplied mainly through the Onyx River and the lake has no outflow. Thus the mass balance of salts in Lake Vanda is very useful for discussing the salt origin.

The present authors determined the partitioning of chemical constituents into mineral fractions for the DVDP 4A core from Lake Vanda and the DVDP 14 core from North Fork, 1.5 km from the western edge of Lake Vanda, by using a selective chemical leaching technique. With this technique, it becomes possible to estimate the amounts of chemical elements contained not only as water soluble salt but also as carbonate or oxide.

This paper discusses the chemical composition of salts in Lake Vanda to find the predominant origin of the salts from the viewpoint of the mass balance.

## 2. Experimental

Samples: DVDP 4A and DVDP 14 were taken for the Dry Valley Drilling Pro-

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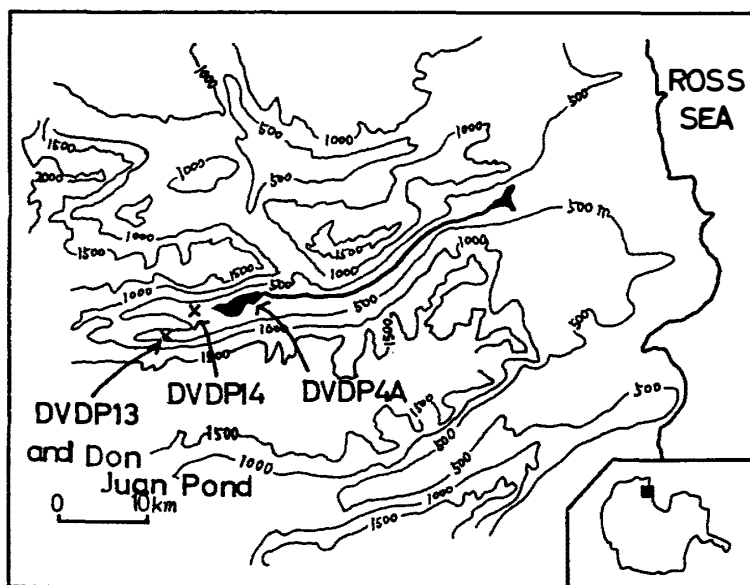


Fig. 1. Sampling stations of DVDP 4A and DVDP 14 in the Wright Valley.

ject, Phase II (1972–1973) and Phase IV (1974–1975), respectively. The sampling locations are shown in Fig. 1. The geological descriptions of these two cores were given by CARTWRIGHT *et al.* (1974) and CHAPMAN-SMITH (1975) (Figs. 2 and 3). For chemical analysis, the samples were dried under vacuum condition, ground slightly in an agate mortar and sieved through a polyethylene sieve (80 mesh).

**Leaching procedure:** The leaching procedure of the water soluble salts was given in the previous paper (TOMIYAMA and KITANO, 1982). Sodium, potassium, calcium, magnesium, chloride and sulfate in the water soluble salts were determined.

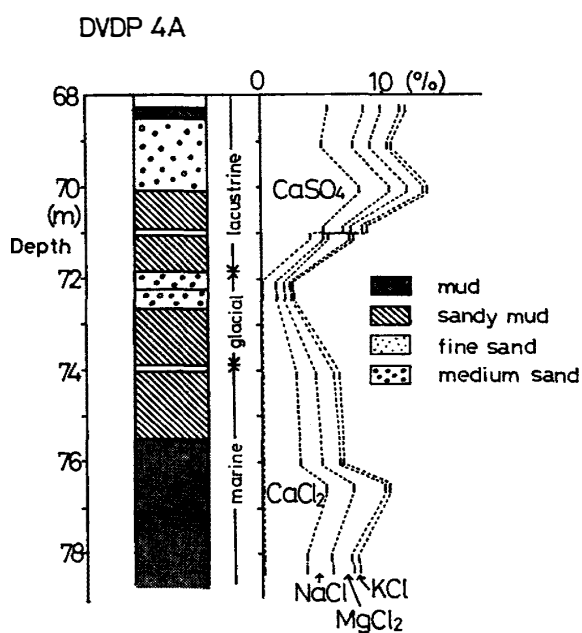


Fig. 2. Geological description and vertical distribution of water soluble salts in DVDP 4A core sediment.

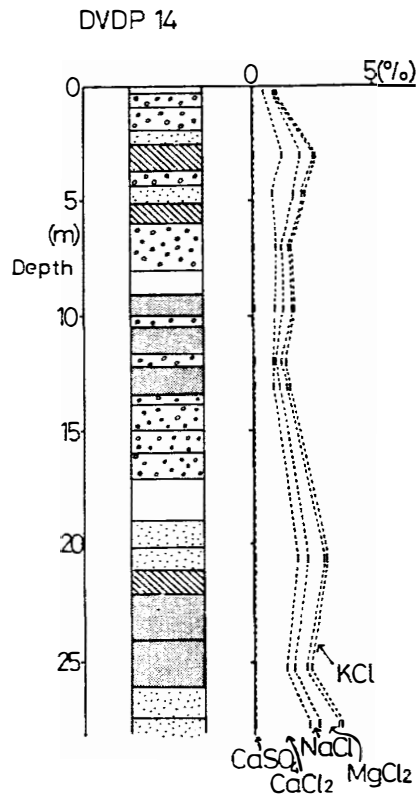


Fig. 3. Geological description and vertical distribution of water soluble salts in DVDP 14 core sediment.

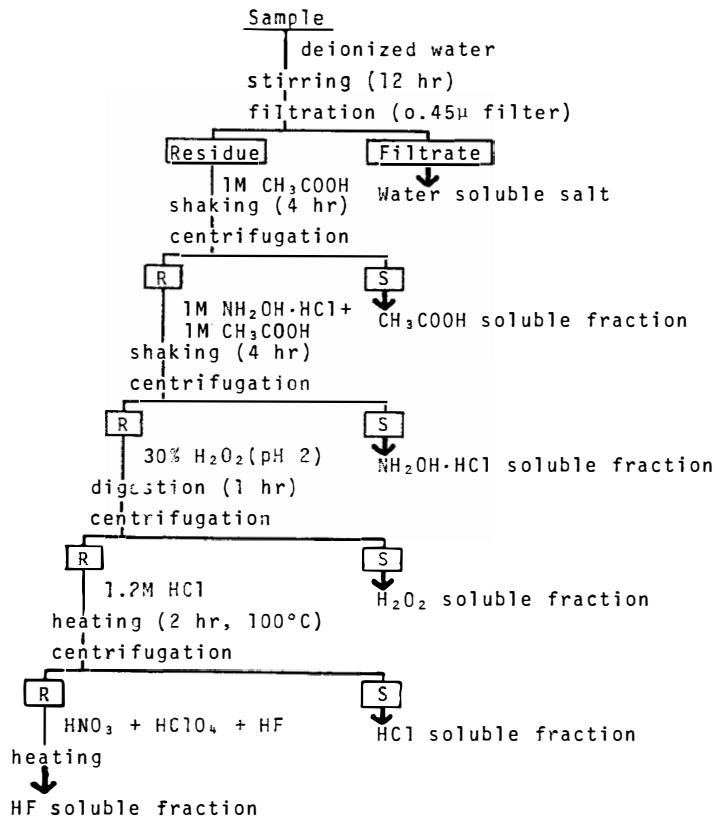


Fig. 4. Analytical procedure for determination of partition of chemical constituents in core sediment samples.

The selective chemical leaching procedure for water insoluble fractions is shown in Fig. 4. This procedure was modified by adding the  $H_2O_2$  treatment to the previous scheme (TOMIYAMA and KITANO, 1982; TOMIYAMA *et al.*, 1983). TORII *et al.* (1975) reported that the bottom water in Lake Vanda contained hydrogensulfide. Therefore, the surface sediment of the DVDP 4A core is assumed to contain sulfide minerals. The digestion procedure with 30%  $H_2O_2$  solution is enough for the dissolution of the sulfide minerals (KITANO *et al.*, 1983). Calcium, magnesium, iron, manganese, copper and zinc dissolved to each fraction were determined by using a Perkin Elmer 503 atomic absorption spectrometer.

### 3. Results and Discussion

#### 3.1. Water soluble fraction

Figures 2 and 3 show the content and the chemical composition of water soluble salts in the sediment cores DVDP 4A and DVDP 14, respectively. The DVDP 4A core was reported to be divisible into three sections according to the diatom analysis (BRADY, 1974, 1979). Figure 2 shows that the major component of the water soluble salt is  $CaSO_4$  in the lacustrine section and  $CaCl_2$  in the other sections. On the other hand, the DVDP 14 core sediment is considered to be glacial or fluvial sediment, because of the absence of diatom. Figure 3 shows that the content of water soluble salts is small in the DVDP 14 core sediment and that  $CaCl_2$  is the major component of the salts.

CARTWRIGHT and HARRIS (1981) reported that saline groundwater has been discharging at the bottom of Lake Vanda. Table 1 shows the chemical compositions of water soluble salt and groundwater in Lake Vanda. The chemical compositions of the water soluble salts in DVDP 14 and in the deeper part of DVDP 4A seem to be similar to that of the groundwater from the DVDP 4A hole. This may indicate that the  $CaSO_4$  was deposited from the lake water as gypsum and  $CaCl_2$  was derived from the groundwater.

Table 1. Ratios of Na, Mg and K to Ca and  $SO_4$  to Cl in groundwater and water soluble salt.

Ratio (mole/mole)	Groundwater DVDP 4A	Salt in DVDP 4A	Salt in DVDP 14
$Na^+/Ca^{2+}$	0.52	0.81	0.47
$Mg^{2+}/Ca^{2+}$	0.51	0.46	0.50
$K^+/Ca^{2+}$	$3.3 \times 10^{-2}$	$8.4 \times 10^{-2}$	0.11
$SO_4^{2-}/Cl^-$	$1.2 \times 10^{-3}$	$3.4 \times 10^{-3}$	$1.9 \times 10^{-3}$

#### 3.2. Water insoluble fraction

Figures 5 to 10 show the results of selective chemical leaching for the sediment cores DVDP 4A and DVDP 14. The abscissa gives their concentrations on the basis of water insoluble portion.

The comparison of the distribution of chemical elements in the DVDP 4A core with that in the DVDP 14 core shows that the DVDP 14 sediment has a quite uniform chemical composition through the core, whereas the DVDP 4A sediment shows some characteristics. The chemical elements can be divided into two (A and B) types from

the distribution. Magnesium and iron are distributed relatively in uniform throughout the core (A type). Calcium, manganese, copper and zinc have some peaks in their distribution (B type). It is recognized from the comparison of Fig. 2 with Figs. 7, 8,

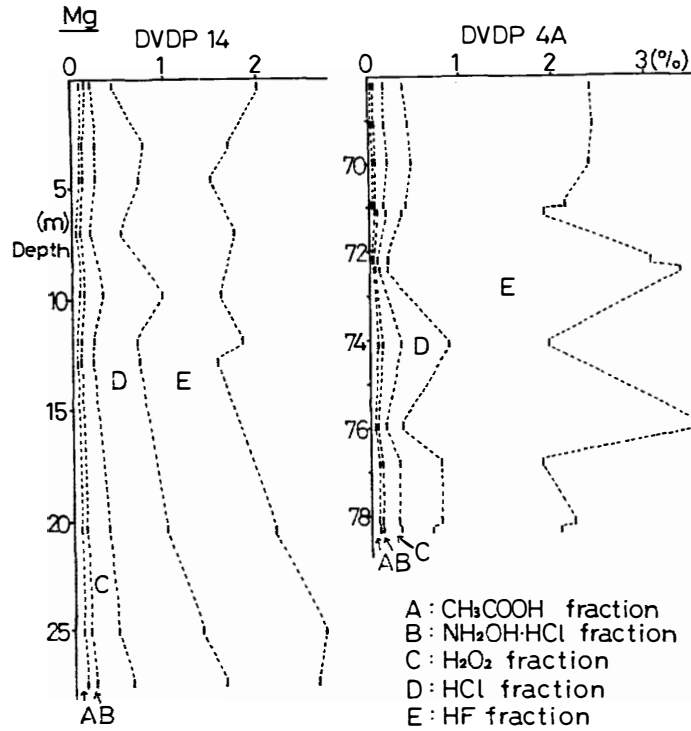


Fig. 5. Vertical distribution of magnesium in water insoluble fraction.

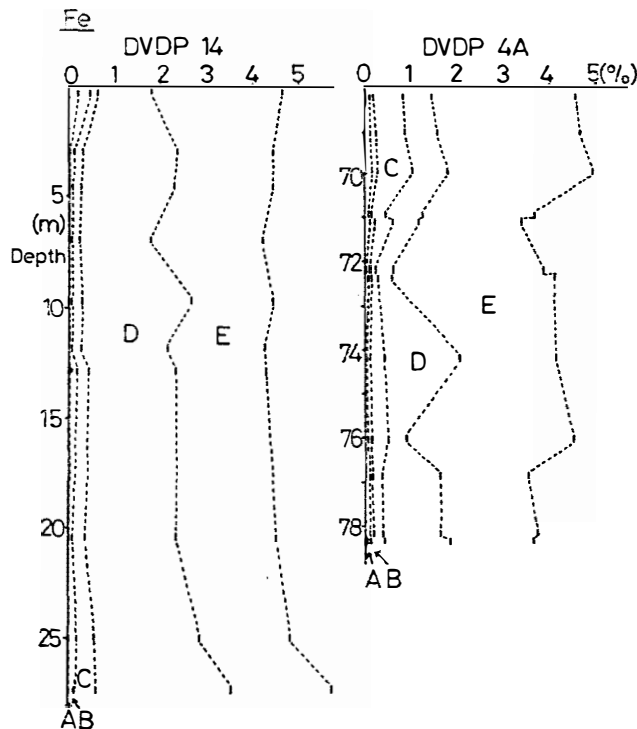


Fig. 6. Vertical distribution of iron in water insoluble fraction.

9 and 10 that calcium and manganese have a peak at the bottom layer of the lacustrine sediment, that copper has a peak at the glacial origin sediment layer and that zinc has a peak at the surface layer of the lacustrine sediment.

### 3.2.1. Magnesium and iron (A type)

The magnesium concentrations in the pond water of Don Juan Pond and in the bottom water of Lake Vanda are relatively small as compared with those of the other elements such as calcium. The mass balance of magnesium is very important for the discussion about the origin of salts in the Wright Valley. The present authors have already reported that there is no evidence of magnesium enrichment in the sediments of Don Juan Pond (TOMIYAMA and KITANO, 1982). Clearly the same trend is observed in the sediments of DVDP 4A and also DVDP 14 (Fig. 5).

It was reported that the bottom water of Lake Vanda contained hydrogensulfide (TORII *et al.*, 1975). This means that sulfate reduction by bacteria occurs in the bottom sediment. The profile of iron in the  $H_2O_2$  soluble fraction of DVDP 4A core (Fig. 6) shows that the lacustrine sediment contains a small amount of iron sulfide.

### 3.2.2. Calcium, manganese, copper and zinc (B type)

Calcium and manganese have a quite similar distribution (Figs. 7 and 8). The profiles of calcium and manganese in the DVDP 4A core show peaks of their contents at a depth of about 3 m. These peaks are due to the layer of concentrated calcium carbonate. Manganese in the  $CH_3COOH$  soluble fraction is considered to be contained mainly in calcium carbonate as a solid solution. The depth of the peak seems to correspond to the depth of the early lacustrine sedimentation stage. The distributions of calcium carbonate in Fig. 7 and of calcium sulfate in Fig. 2 may indicate that the lake water was concentrated through evaporation at the early stage of the forma-

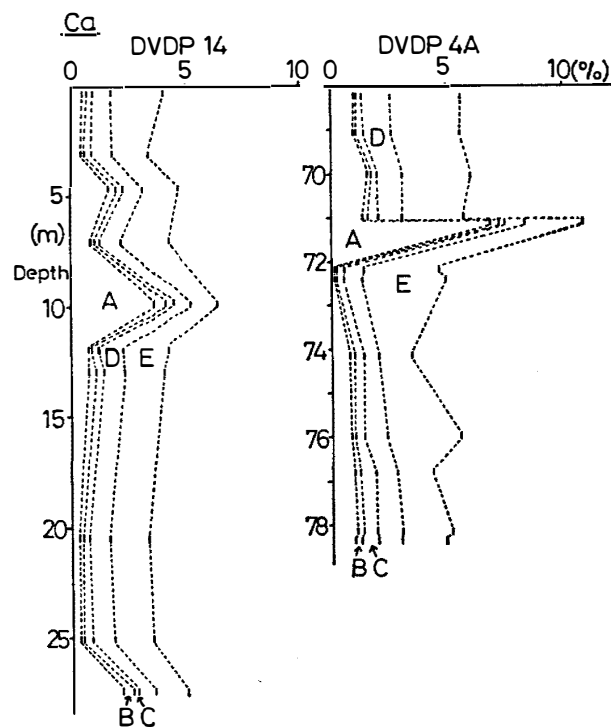


Fig. 7. Vertical distribution of calcium in water insoluble fraction.

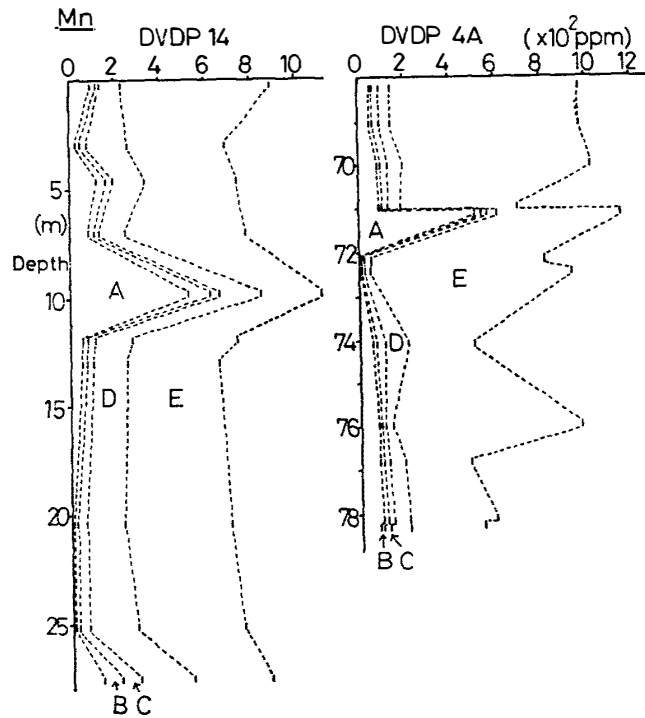


Fig. 8. Vertical distribution of manganese in water insoluble fraction.

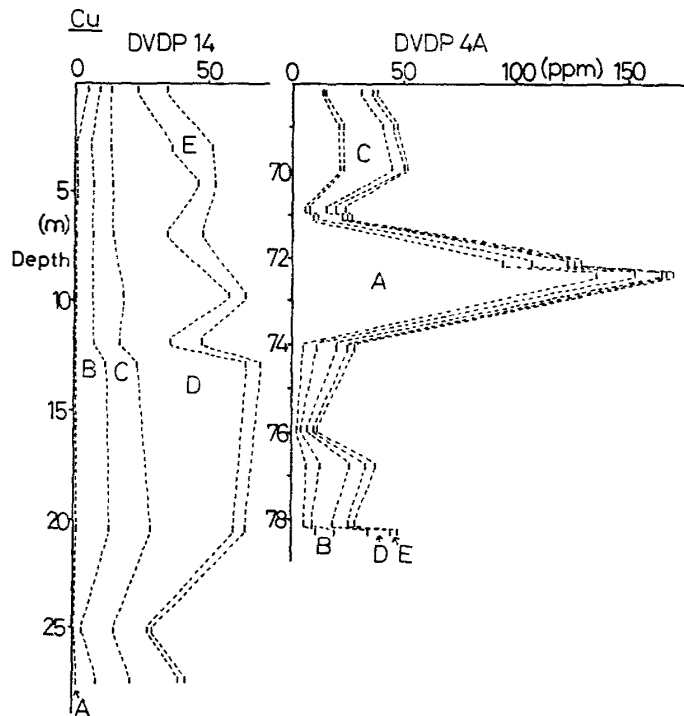


Fig. 9. Vertical distribution of copper in water insoluble fraction.

tion of Lake Vanda. It is assumed that firstly calcium carbonate was deposited from the lake water, and then calcium sulfate was deposited. The crystal form of the calcium carbonate at the depth of 3 m is calcite. Thus, the lake water at an early stage

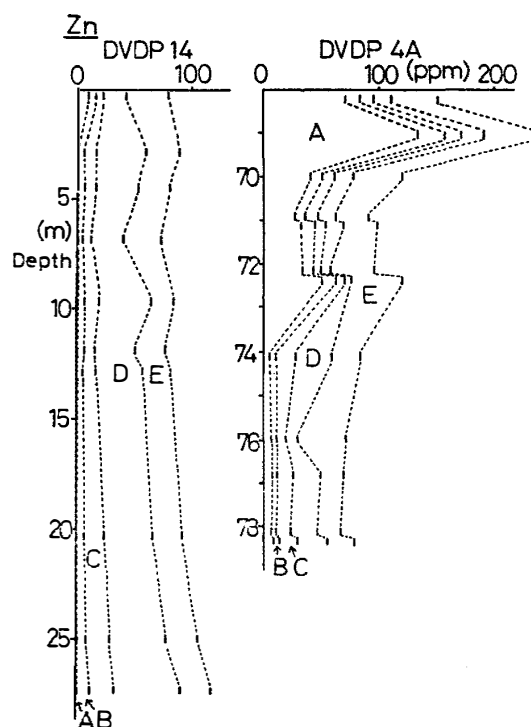


Fig. 10. Vertical distribution of zinc in water insoluble fraction.

of Lake Vanda is supposed to have been calcium-rich water (TOMIYAMA and KITANO, 1984).

The calcium profile in DVDP 14 also shows a calcium carbonate concentrated layer at about a 10 m depth. This distribution has no relation with the distribution of water soluble calcium salts in Fig. 3.

The profiles of copper and zinc are very interesting. Copper was concentrated in the  $\text{CH}_3\text{COOH}$  soluble fraction at the layer of glacial sediment (about 4 m in depth, Fig. 9), and zinc in the  $\text{CH}_3\text{COOH}$  soluble fraction at the layer of lacustrine sediment about 1 m in depth, Fig. 10). This difference between copper and zinc is remarkable. The chemical constituents dissolved to  $\text{CH}_3\text{COOH}$  solution are regarded to be contained in carbonate and/or ion-exchangeable fraction. In other words, a large amount of easily labile copper exists in the glacial sediment and easily labile zinc exists abundantly in the lacustrine sediment. The origin and the behavior of copper and zinc must be investigated.

The sediment in DVDP 14 was considered to be glacial or fluvial. However, judging from the results of partitioning of each element, the sediment in DVDP 14 appears to be fluvial. In the glacial origin sediment layer of DVDP 4A the amount of calcium and manganese contained in the  $\text{CH}_3\text{COOH}$  soluble,  $\text{NH}_2\text{OH}\cdot\text{HCl}$  soluble and  $\text{H}_2\text{O}_2$  soluble fractions were smaller than those in the other sediment layers, and the amounts of copper and zinc contained in those fractions of glacial sediment were larger than those of marine sediment. The partitioning of these elements in the DVDP 14 sediment is similar to that of marine sediment rather than that of glacial sediment. It is supposed that the cause of the different partitioning of each element between glacial sediment and other sediment is whether or not the sediment has been exposed to water.



Thus, the DVDP 14 sediment is supposed to have been exposed to water.

### 3.3. Mass balance of salts in Lake Vanda

Lake Vanda is situated at the lowest basin in the Wright Valley. The Onyx River flows into the lake from the east. To clarify the mass balance of salts in Lake Vanda would be useful for determining the salt origin in the Wright Valley.

#### 3.3.1. Estimation of the total amount of salts in Lake Vanda

##### 1) Amounts of salts in sediment

The amount of salts in sediment was calculated by using the analytical data of DVDP 4A. The following assumptions are used.

(a) Salts are deposited only on a deeper bottom floor than 60 m. The area of the deeper bottom floor is estimated to be 1.29 km<sup>2</sup>; NELSON and WILSON (1972) reported that the sediments shallower than 60 m consist mainly of quartzo-feldspathic sand (the mean grain size is 0.25 to 1.00 mm) overlain by a lighter colored layer of biological detritus. They also reported that the sediments below 60 m consist of sandy mud (the mean grain size is 0.125 to 0.5 mm) containing the banded layers of calcite and gypsum.

(b) The water soluble salt content is 10% in the upper 4 m of the sediment, and the salt is composed of CaSO<sub>4</sub> 55%, CaCl<sub>2</sub> 23%, NaCl 10%, MgCl<sub>2</sub> 11% and KCl 1%.

(c) The specific gravity of the sediment is 2.

(d) The water content of the sediment is 30%.

(e) The carbonate content of the sediment is 1.5% in the water insoluble portion.

Thus, the amounts of chemical constituents of the sediment in Lake Vanda were calculated as follows: Ca  $2.1_6 \times 10^5$  t, Na  $2.8_4 \times 10^4$  t, Mg  $2.0_1 \times 10^4$  t, K  $3.7_8 \times 10^3$  t, Cl  $2.1_3 \times 10^5$  t and SO<sub>4</sub>  $2.8_0 \times 10^5$  t.

##### 2) Amounts of chemical constituents in the lake water

The concentrations of chemical constituents at various depths of the stratified

Table 2. Chemical composition of lake water in Lake Vanda (TORII et al., 1975).

Depth (m)	Ca <sup>2+</sup> (g/kg)	Na <sup>+</sup> (g/kg)	Mg <sup>2+</sup> (g/kg)	K <sup>+</sup> (g/kg)	Cl <sup>-</sup> (g/kg)	SO <sub>4</sub> <sup>2-</sup> (g/kg)
3.9	0.042	0.031	0.005	0.008	0.154	0.012
5.8	0.057	0.066	0.013	0.015	0.186	0.013
7.7	0.061	0.057	0.015	0.013	0.204	0.013
11.6	0.071	0.057	0.017	0.008	0.234	0.018
13.5	0.092	0.075	0.022	0.011	0.302	0.020
28.6	0.172	0.116	0.043	0.016	0.548	0.031
41.9	0.275	0.140	0.073	0.032	0.880	0.034
50.3	2.30	0.719	0.667	0.071	7.11	0.074
52.2	5.09	1.40	1.48	0.125	15.43	0.130
54.1	8.30	2.20	2.43	0.212	24.95	0.199
55.1	10.16	2.78	3.15	0.224	30.87	0.246
57.9	15.56	3.92	4.82	0.413	46.94	0.396
59.9	18.07	5.55	5.66	0.415	54.04	0.473
64.6	24.40	6.11	7.40	0.590	74.28	0.615

lake water were reported by TORII *et al.* (1975), as shown in Table 2. The total amounts of individual constituents in the lake water were calculated by using those data. In the calculation, it is assumed that the stratification of each chemical constituent occurs all over the lake.

The results of calculation are as follows: Ca  $3.6_9 \times 10^5$  t, Na  $1.0_8 \times 10^5$  t, Mg  $1.1_1 \times 10^5$  t, K  $1.1_0 \times 10^4$  t, Cl  $1.1_2 \times 10^6$  t and SO<sub>4</sub>  $1.2_7 \times 10^4$  t.

The amounts of individual chemical constituents in Lake Vanda were calculated from the above results. Table 3 summarizes these results.

Table 3. Estimation of total amount of salt in Lake Vanda.

	Sediment (t)	Lake water (t)	Total (t)
Ca <sup>2+</sup>	$2.1_6 \times 10^5$	$3.6_9 \times 10^5$	$5.8_5 \times 10^5$
Na <sup>+</sup>	$2.8_4 \times 10^4$	$1.0_8 \times 10^5$	$1.3_6 \times 10^5$
Mg <sup>2+</sup>	$2.0_1 \times 10^4$	$1.1_1 \times 10^5$	$1.3_1 \times 10^5$
K <sup>+</sup>	$3.7_8 \times 10^3$	$1.1_0 \times 10^4$	$1.4_8 \times 10^4$
Cl <sup>-</sup>	$2.1_3 \times 10^5$	$1.1_2 \times 10^6$	$1.3_3 \times 10^6$
SO <sub>4</sub> <sup>2-</sup>	$2.8_0 \times 10^5$	$1.2_7 \times 10^4$	$2.9_3 \times 10^5$

### 3.3.2. Sources of salts in Lake Vanda

The origin of salts in the Dry Valleys region has been studied by many researchers. Some conceivable origins have been proposed as follows: (1) trapped seawater, (2) sea spray, (3) aerosol, (4) groundwater and (5) rock weathering. In all cases, salts must be transported with water.

For Lake Vanda, the Onyx River is the most important source of water. The water source of the Onyx River is melt water from the Wright Lower Glacier and the other alpine glaciers (CHINN, 1981). And the river flows for a distance of about 28 km from the Upper Wright Glacier to Lake Vanda. Therefore, the dissolved chemical constituents in the Onyx River water are considered to have been derived from aerosol and sea spray contained in snow and ice, from dry fallout and from rocks through chemical weathering with melt water. On the mass balance of chemical constituents in Lake Vanda, the input of chemical constituents through the Onyx River is considered to include chemical constituents from the above three salt origins.

However, the input of salts through the Onyx River is not sufficient for the explanation on the amounts of all salts in Lake Vanda, because the concentration of

Table 4. Calculated values of total amount of salt in Lake Vanda and chemical composition of Onyx River water, groundwater and seawater.

	Total salt (t)	Onyx River* (mg/kg)	Groundwater (g/kg)	Seawater (g/kg)
Ca <sup>2+</sup>	$5.8_5 \times 10^5$	6.8	37.2	0.412
Na <sup>+</sup>	$1.3_6 \times 10^5$	5.0	11.2	10.8
Mg <sup>2+</sup>	$1.3_1 \times 10^5$	1.3	11.3	1.29
K <sup>+</sup>	$1.4_8 \times 10^4$	1.0	1.19	0.399
Cl <sup>-</sup>	$1.3_3 \times 10^6$	6.9	123	19.4
SO <sub>4</sub> <sup>2-</sup>	$2.9_3 \times 10^5$	6.2	0.4	2.71

\* Average value of data on 26 Dec. 1971, 26 Dec. 1972 and 17 Jan. 1973.

chloride ions in the Onyx River water is too small to account for such a large quantity of chloride ions in the salts of Lake Vanda (Table 4). Therefore, the contribution from chloride-rich water such as seawater or groundwater must be taken into consideration. Table 4 also shows the concentrations of major chemical constituents in the groundwater, which were measured by CARTWRIGHT and HARRIS (1981). The groundwater was considered to exist and flow under Lake Vanda.

Now, the following simple simultaneous equations are used in order to know which water (seawater itself or groundwater) is dominant as a source of chloride ion:

$$\begin{cases} a_1X + b_1Y = K_1 \\ a_2X + b_2Y = K_2, \end{cases}$$

where  $a_1$  and  $a_2$  are the concentrations of elements 1 and 2 in the Onyx River water respectively,  $b_1$  and  $b_2$  are the concentrations of elements 1 and 2 in seawater itself (or the groundwater of Lake Vanda) respectively,  $X$  is the quantity of the Onyx River water,  $Y$  is the quantity of seawater itself (or the groundwater), and  $K_1$  and  $K_2$  are the total amounts of elements 1 and 2 in Lake Vanda respectively.

Here, chlorine and magnesium are used as elements 1 and 2 respectively, because chloride ion is a representative anion in salt and water and the mass balance of magnesium is very important as described earlier and all of magnesium ion exists only in the water and the sediment of Lake Vanda. It was reported by NISHIYAMA (1977) that calcite and gypsum were found but magnesium salt was not found in the surrounding areas of Lake Vanda.

If  $b_1$  and  $b_2$  are the concentrations of seawater itself, the  $Y$  value becomes negative. For the groundwater the results become as follows:

$$\begin{cases} X = 1.4 \times 10^{10} \text{ t} \\ Y = 1.0 \times 10^7 \text{ t} \end{cases}$$

These approximate estimates may indicate that the input of chemical constituents through the Onyx River is important as a salt source in Lake Vanda and also that the discharge of the groundwater to Lake Vanda cannot be neglected. CHINN (1981) reported that the annual flow of the Onyx River into Lake Vanda in the summer season varies considerably, from  $1 \times 10^6$  to  $15 \times 10^6$  t/year with an average flow of  $2 \times 10^6$  t/year (1969–1981). By using these amounts of annual flow, the age of Lake Vanda is calculated to be about 7000 years from  $2 \times 10^6$  t/year, 14000 years from  $1 \times 10^6$  t/year and about 1000 years from  $15 \times 10^6$  t/year. The estimated average value of age (7000 years) seems reasonable, considering the variation of the annual flow of the Onyx River and comparing with the minimum age (about 3600 years) estimated from uranium analysis by KOMURA (personal communication). WILSON (1964) and MATSUBAYA *et al.* (1979) reported that the flow of water into Lake Vanda was increased about 1200 years ago by a climatic change, and also reported that the stratification of salinity in the Lake Vanda water resulted from such a change. The age of Lake Vanda, 7000 years, does not mean the history of stratification but a period of salt accumulation. Thus, the discussion by WILSON and MATSUBAYA is not considered to conflict with the present author's result on age.

Table 5 shows the calculated values of each element by using the above two values. The comparison of the calculated values with the total amounts of each element estimated from analytical data indicates that the quantities of major elements except for

Table 5. Comparison of total amount of salt in Lake Vanda with the calculated value by using  $X$  and  $Y$  values.

	Total amount of salt in Lake Vanda	Calculated value		
		From Onyx River ( $X=1.4 \times 10^{10}$ )	From groundwater ( $Y=1.0 \times 10^7$ )	Total
Ca <sup>2+</sup>	$5.8_5 \times 10^5$	$9.6 \times 10^4$	$3.7 \times 10^5$	$4.7 \times 10^5$
Na <sup>+</sup>	$1.3_6 \times 10^5$	$7.0 \times 10^4$	$1.1 \times 10^5$	$1.8 \times 10^5$
Mg <sup>2+</sup>	$1.3_1 \times 10^5$	$1.8 \times 10^4$	$1.1 \times 10^5$	$1.3 \times 10^5$
K <sup>+</sup>	$1.4_8 \times 10^4$	$1.4 \times 10^4$	$1.2 \times 10^4$	$2.6 \times 10^4$
Cl <sup>-</sup>	$1.3_3 \times 10^6$	$9.7 \times 10^4$	$1.2 \times 10^6$	$1.3 \times 10^6$
SO <sub>4</sub> <sup>2-</sup>	$2.9_3 \times 10^5$	$8.7 \times 10^4$	$4.0 \times 10^3$	$9.1 \times 10^4$
Fe	$3.0 \times 10^4$	$7.0 \times 10^3$	?	
Mn	$1.0 \times 10^3$	$1.4 \times 10^2$	?	

sulfate ions can be explained with these two sources, the Onyx River water and the groundwater. The disagreement for sulfate ions may be attributed to the diverse analytical data of sulfate ions in the Onyx River water (e.g., it was reported from 2.3 to 12.6 mg/kg), and also attributed to the existence of sulfate salts such as CaSO<sub>4</sub> and Na<sub>2</sub>SO<sub>4</sub> around Lake Vanda (NISHIYAMA, 1977).

It seems also useful to calculate the mass balance of heavy metals in Lake Vanda. The profiles of heavy metal contents in DVDP 4A core (Figs. 6, 8, 9 and 10) indicate that the distributions of copper and zinc are too complicated to evaluate their amounts in the sediment uptaken from the lake water. Therefore, the mass balance of iron and manganese was discussed.

The amounts of iron and manganese in the sediment uptaken from the lake water were calculated as follows: iron and manganese dissolved to the CH<sub>3</sub>COOH, NH<sub>2</sub>OH·HCl and H<sub>2</sub>O<sub>2</sub> soluble fractions were regarded to be contained in the post-sedimentary portions of the lacustrine sediment. In this calculation, the iron and manganese contents of these fractions in the glacial sediment (from 4 m down to 6 m in depth) were considered as the amounts of them originally contained in sediment. Therefore, they were subtracted from those of the lacustrine sediment. The other assumptions were the same as those described in 3.3.1. As the result of the calculation, it is found that  $3.0 \times 10^4$  t of iron and  $1.0 \times 10^3$  t of manganese have been uptaken from the lake water to the sediment. Next, the amounts of iron and manganese contained in the present lake water were calculated to be 4 and 12 t respectively by using the data by MASUDA *et al.* (1982). After all, the total amounts of iron and manganese existing in the Lake Vanda area were calculated to be  $3.0 \times 10^4$  and  $1.0 \times 10^3$  t respectively. On the other hand, by using the total flow of the Onyx River water for these 7000 years ( $1.4 \times 10^{10}$  t), the amounts of iron and manganese supplied for these 7000 years through the Onyx River water were calculated to be  $7.0 \times 10^3$  and  $1.4 \times 10^2$  t respectively, where their concentrations in the river water were 500 and 10 ppb respectively. Unfortunately, the concentration data of heavy metals in the groundwater are not available. Therefore, the amounts of heavy metals supplied through the groundwater cannot be estimated. However, from the above calculation, it is assumed that  $2.3 \times 10^4$  t of iron

and  $8.6 \times 10^2$  t of manganese might have been transported during these 7000 years to Lake Vanda through the groundwater.

The origin of the groundwater in Lake Vanda has not been clarified. But it may be the water which has been under water-rock interaction for a long time under the ground.

The survey for the groundwater is necessary for the understanding of the salt origin in the Wright Valley.

#### 4. Conclusion

The analysis of DVDP 4A and DVDP 14 core sediment by using the selective chemical leaching technique revealed the distribution of chemical elements in detail. The distribution of each element indicated that the sediment is clearly lacustrine, glacial or fluvial. From the calculation of the mass balance of salts in Lake Vanda, the age of Lake Vanda is estimated to be about 7000 years and the contribution of the groundwater as well as of the Onyx River water is very important as a salt source in Lake Vanda.

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