Report of the Japanese Summer Parties in Dry Valleys, Victoria Land, 1963-1965
V. Chemical Composition of Lake Waters

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南極 Victoria Land の Dry Valley 調査報告
V. 湖 水 の 化 学 成 分

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要 旨

1963年から1965年の間に Victoria Land の Dry Valley にあるいくつかの湖について調査した結果, 湖水の化学成分はそれが存在する谷によってそれぞれ特徴があり, 化学組成は地域によってかなり異なっていることが判明した. Wright Valleyにある Don Juan Pond およびLake Vanda では Ca と Cl か最も多いか, 一つ南隣の谷, Taylor Valley にある Lake Bonney では Mg と Cl, 次に Na が多く, 毎に近い Lake Fryxell では Na と Cl が最も多く含まれている. その他, さらに南に位置する地域にある湖の多くは淡水湖てあった.

これらの湖の化学成分を主として報告する.

1. Introduction

According to TEDROW et al. (1963), only a fragmentary information on a number of saline lakes in Antarctica had been found in literature before the Antarctic summer of 1960–61 (MARKOV, 1956; GLAZOVSKAJA, 1958; BALL and NICHOLS, 1960; McKELVEY and WEBB, 1961). The first limnological reconnaissance of the Lakes Bonney and Vanda in southern Victoria Land was conducted by the University of Kansas group (ARMITAGE and HOUSE, 1962; ANGINO and ARMITAGE, 1963) in the Antarctic summer of 1960–61. Prior to this visit, no definite proof for a great amount of water beneath the ice cover of these lakes was available. ANGINO and his collaborators made further observations in the Antarctic summer of 1961–62, and during this period another party from the Victoria University of Wellington, N. Z. also examined the physics and chemistry of Lake Vanda (WILSON and WELLMAN, 1962).

Thus, the characteristic feature of the lakes, with their salinity and high temperature, was highlighted as a greatly interesting problem.

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2. Preliminary Survey

The main purpose of the reconnaissance in 1963–64 performed by the Japanese Summer Party was to study the general physico-chemical features of the lakes as well as the environmental factors which may govern the ecology of the lakes.

Three, two and one holes in Lakes Vanda, Bonney and Fryxell, respectively, were used for the sampling of water. The locations of hole Nos. C1 and C2 (bottom depth 10 and 15m, respectively) in Lake Vanda are somewhere around No. V12 of 1965–66, and No. C3 is around No. V3 of 1964–65. Two holes in Lake Bonney were both in the east lobe. Holes Vanda C3 and Bonney B1 and B2 had been cored already by the New Zealand Party at the time of our visit (Hoare et al., 1964).

The results of chemical analysis are tabulated in Table 1 together with pertinent data. The data contain also those for the Don Juan Pond and two small ponds in the South Fork, Wright Valley. Table 2 shows the deuterium content in lake waters, and Table 3 the boron content The data include the results for some other land waters in the vicinity. The deuterium content of saline waters except in Don Juan Pond seems to be considerably lower than that in ponds in Capes Royds and Evans. The boron:chlorine ratio in saline deep waters in Lakes Vanda and Bonney is considerably lower than in oceanic water, but waters in Lake Fryxell and most of the ponds in Capes Royds and Evans indicate similar values to that in oceanic water.

Table 4 tabulates the rubidium and cesium contents of the saline waters determined by a neutron activation method (Yamagata et al., 1962) Similarity between the water of Lake Fryxell and sea water in relative concentrations of the alkali metal elements is in contrast with dissimilarity between the water of Don Juan Pond and sea water. Potassium is relatively concentrated in Don Juan Pond with respect to sodium, while rubidium and cesium are concentrated relatively to potassium, if the sea water is assumed as the basis.

A carcass of crab-eater seal (Lobodon carcinophagus) found in the vicinity of Don Juan Pond was brought back to Tokyo (Photo 1) and the age determination was made by Prof. K. Kigoshi, Gakushuin University. Carbon-14 dating showed an age of 1210±120 years. However, living fishes caught in the Ross Sea at a fish-hole near McMurdo Station gave an age of 1610±90 years, suggesting a peculiar ecological condition in Antarctica, so that the validity of carbon–14 dating of specimens from Antarctica is quite dubious. Remains of algae collected at Cape Evans also showed an age of 1570±90 years.

Table 1. *Chemical analyses of land waters in Victoria Land and Ross Island, Antarctica.*

Locality	Time of collection	Depth (m)	pH	Temp. (°C)	Na (mg/kg)	K (mg/kg)	Mg (mg/kg)	Ca (mg/kg)	Cl (mg/kg)	SO₄ (mg/kg)
Lake Vanda Edge	Dec. 28, 1963	0	7.8	2.00	15 0	5.3	5.6	23.9	80.1	6
// C1	Dec. 29, 1963	5	8.4	4.38	35.0	10.5	12.0	49.4	166 0	13
// C1	//	10	8.4	4.99	42.0	12.0	14 3	59.8	195.7	16
// C2	//	5	7 4	4.49	15.0	4.5	5 3	26 5	92.1	8
// C2	//	15	7 4	7.42	72.5	23.5	33.7	138.4	443.2	20
// C3	Jan. 15, 1964	5	–	4 36	29.0	8.8	11.8	44.7	149 0	9
// C3	//	30	–	6.90	109	31	44.2	184	585	25
// C3	//	45	–	8.39	750	175	1,020	3,600	11,350	89
// C3	//	63	–	23.20	6,554	726	7,170	22,730	72,150	641
Lake Bonney B1	Jan. 1, 1964	5	8.2	–	273	17.4	32 5	25.9	301.5	54
// B1	//	14	6.9	–	15,220	1,190	15,880	1,010	80,140	2,556
// B2	//	5	7.6	0.47	148.5	11.4	18.0	21.0	209.0	44
// B2	//	14	7.0	6.95	17,030	1,224	14,320	980	72,870	2,440
// B2	//	30	7 6	−1.21	35,620	2,714	21,420	1,090	116,000	2,570
// Inflow	Jan. 2, 1964	0	–	–	8.0	3.2	4.8	14.2	17.4	8
Lake Fryxell	Jan. 4, 1964	4	7.9	–	58.0	6.0	8.7	9.6	105.0	11
//	//	10	7.5	–	1,240	104	156.1	97.0	1,828	159
//	//	18	7.4	–	2,840	196	342	128	3,871	116
Don Juan Pond	Dec 30, 1963	0	–	6.45	2,161	231	2,590	130,500	250,500	0
South Fork (1)	//	0	–	–	244	13 8	78.5	57.2	306.0	228
// (2)	//	0	–	–	17.5	1 3	9.4	10 3	36 0	25

Table 2   Deuterium content of land waters in Victoria Land and Ross Island
(by Prof. K AMBE, Ochanomizu Women's University).

Locality			D_{Tokyo} %	D_{SMOW} %
Lake Vanda	Edge		−19 5	−23 5
	C1	5m	−18 9	−22 9
	C1	10m	−17 9	−22 0
	C2	5m	−19 2	−23.2
	C2	15m	−18 9	−22 9
	C3	5m	−19.4	−23 4
	C3	30m	−22.2	−26 1
	C3	45m	−17 6	−26 7
	C3	63m	−20 6	−24 5
Lake Bonney	B1	5m	−23 8	−27 6
	B1	14m	−26 4	−30 1
	B2	5m	−20 6	−24 5
	B2	14m	−28 4	−32 0
	B2	30m	−23 7	−27.5
	Inflow		−17 5	−21 6
Lake Fryxell		4m	−17.8	−21 9
		10m	−21 6	−25.5
		18m	−20.4	−24.3
Don Juan Pond			−14 4	−18 6
South Fork (1)			−12.9	−17.2
(2)			−11 5	−15.9
Cape Royds	St 26		− 7 6	−12 2
	Home Lake		− 7 9	−12 4
	Blue Lake		−14 2	−18 5
Cape Evans	Skua Lake		−14.4	−18.6
	St 15		−16 4	−20 5
	St 17		−13 1	−17 4
	St 18		−14 8	−19 0
	St 19		−14 8	−19 0
	St 20		−10.7	−15.1
McMurdo Cinder-cone			−18 7	−22 7
Stranded Moraines			−15 8	−20 0
Ice sheet C1	5		−19 7	−23 7
C1	7		−20 8	−24.7
C1	8		−19.9	−23 9
C1	9		−21.5	−25 4
C1	10		−14 9	−19 1
Snow			−21.7	−25.6

Table 3. Boron content of land waters (by Prof. S. MUTO,
Yokohama National University).

Locality			B mg/l	B : Cl
Lake Vanda	C2	15m	0.032	7.2×10^{-5}
	C3	30m	0.042	7.2×10^{-5}
	C3	45m	1.7	1.5×10^{-4}
	C3	63m	2.4	3.1×10^{-5}
Lake Bonney	B1	5m	0.042	1.4×10^{-4}
	B1	14m	2 9	3.3×10^{-5}
	B2	5m	0.074	3.5×10^{-4}
	B2	14m	1 7	2.1×10^{-5}
	B2	30m	3.8	2.9×10^{-5}
Don Juan Pond			2.0	$5 8 \times 10^{-6}$
South Fork (1)			0.29	9.4×10^{-4}
Cape Royds	St. 26		0.13	$3 2 \times 10^{-5}$
	Home Lake		0.25	$2 4 \times 10^{-4}$
Cape Evans	St. 15		0 24	$1 6 \times 10^{-4}$
	St. 17		0.41	$1 7 \times 10^{-4}$
	St. 18		0 23	4.3×10^{-4}
	St. 19		0.46	$1 7 \times 10^{-4}$
	St. 20		0.60	$9 9 \times 10^{-5}$
Oceanic water 19‰			4.6	2.4×10^{-4}

Table 4. Rubidium and cesium contents of the saline waters (by N. YAMAGATA).

Element or ratio	Don Juan Pond	Lake Bonney B2 30m	Lake Vanda C3 63m	Lake Fryxell 18m	Sea water
Cl mg/kg	250,500	116,000	72,150	3,871	18,980
Na 〃	2,161	35,620	6,554	2,840	10,556
K 〃	231	2,714	726	196	380
Rb μg/kg	598	605	170	34	128
Cs 〃	84	81	59	4.4	9.8
K/Na	0 107	0 076	0.111	0.069	0.0360
Rb/K $\times 10^4$	26	2.2	2 3	1 8	3.4
Cs/K $\times 10^5$	36	3.0	8.1	2.3	2.6
Cs/Rb	0.14	0.13	0 35	0.13	0 076

3. General Aspect of Chemical Composition of Saline Waters

Figure 1 visualizes the main ionic composition of the saline waters in comparison with sea water. Compositions of two saline waters are also shown for comparison. One of them, Deep Lake, is among the saline lakes of the Vestfold Hills, Princess Elizabeth Land (McLEOD, 1963) and the other one, Dead Sea, is a representative salt lake in arid zone in lower latitudes.

With the exception of Lake Fryxell, all of the deepest waters in the saline lakes have a larger salinity than sea water. Cationic composition in Lake Fryxell is quite similar to that in sea water, while the anionic composition indicates an increase in bicarbonate ion and a depletion in sulfate ion. The depletion in sulfate and sodium ions is common in all of the saline lakes. With respect to the Mg:Ca ratio, a gap is found between two groups of lakes, one group including Lake Vanda and Don Juan Pond, and the other comprises all the rest. A depletion in magnesium ion is noticed relative to calcium. Thus, assuming that the original composition of the saline water was the same as that of sea water and that the concentration was progressive, the mechanism of changes in chemical composition may be generalized. The principal changes which may occur progressively can be described as follows.

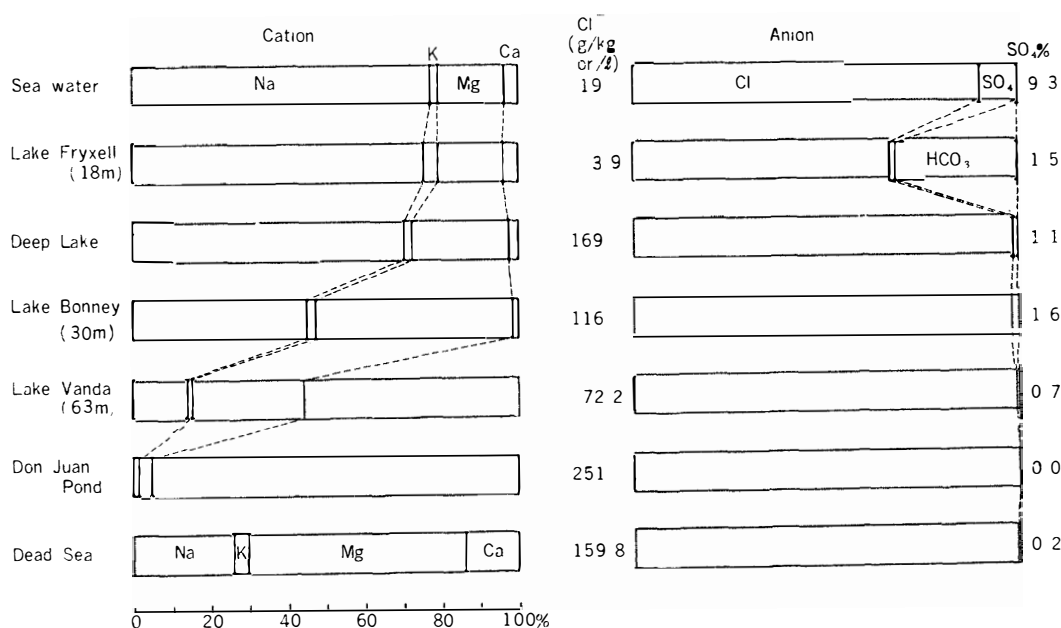1. Progressive decrease in sulfate relative to chloride ion.

Fig 1. Per cent composition in equivalent of ions in saline waters

2. Decrease in calcium relative to magnesium ion in earlier stages.

3. Progressive decrease in sodium ion.

4. Decrease in magnesium ion relative to calcium in later stages.

4. Deposition of Salts from Sea Water under Frigid Conditions

The deposition of salt by evaporation of sea water under normal temperature was extensively studied by many investigators in relation to the oceanic salt deposits and the manufacturing of common salt. The order of deposition by the evaporation of sea water as reported by USIGLIO (1849) is $CaCO_3 - CaSO_4 - NaCl - (MgSO_4)$ and the resultant brine contains large quantities of $MgCl_2$ and $MgSO_4$ (Table 5).

When sea water is concentrated under frigid conditions, namely, by freezing and removal of ice, the order of deposition of the salts is quite different (THOMPSON and NELSON, 1956), that is, $(CaCO_3) - Na_2SO_4 \cdot 10H_2O - NaCl \cdot 2H_2O$ – potassium and magnesium salts (and probably $MgSO_4$), and the remaining brine is composed of calcium chloride in a large proportion. This difference in the order of deposition between evaporation and freezing is due principally to different temperatures of solubilites of $CaSO_4$, Na_2SO_4 and $MgSO_4$.

Table 5. Deposition of the salts by evaporation of sea water (USIGLIO, 1849)

Sp. gr. of brine	Volume (ml)	CaCO₃ (g)	CaSO₄ (g)	NaCl (g)	MgSO₄ (g)	MgCl₂ (g)	NaBr (g)	KCl (g)
1 026	1,000							
1.050	533	0.064						
1.126	190	0 053	0.56					
1.160	145		0 56					
1 175	131		0 18					
1 202	112		0.16					
1 214	95		0.15	3.26	0 004	0 008		
1.221	64		0.15	9.65	0.01	0 04		
1 236	36		0 07	7.90	0 03	0.04	0 07	
1 257	30.2		0 01	2.63	0.02	0 02	0.04	
1.278	23.0			2.27	0 03	0.02	0 05	
1.307	16.2			1.40	0.54	0.03	0 06	
Total deposited salts		0.12	1.75	27.11	0.634	0.158	0 22	
Salts in brine				2.59	1.86	3.16	0.33	0 53
Total		0.12	1.75	29.70	2.494	3.318	0 55	0.53

Under the conditions of Antarctica, it would be more reasonable to suppose a frigid condition than normal evaporation, and if so, the deposition of mirabilite

($Na_2SO_4 \cdot 10H_2O$) would have occurred. In fact, the presence of such deposits was confirmed by McLEOD (1963) in the Vestfold Hills, forming a layer about 10m long, 5m wide and at least one meter thick. It was reported also by the Japanese Summer Parties in the Miers Valley as mentioned previously (TORII et al., 1966).

When the concentration of sea water under frigid conditions is assumed, the changes of chemical composition of the water would exactly follow the course of No. 1–No. 4 as described in the foregoing chapter, and the peculiar chemical composition of Don Juan Pond (see Table 7) would indicate the last stage of concentration. If evaporation was assumed as the cause of concentration, the brine of the last stage should have been composed of $MgCl_2$ and KCl (Table 5).

Freezing temperature of saturated calcium chloride solution is --54°C (THOMPSON and NELSON, 1956). Therefore, it is supposed that Don Juan Pond will never freeze even in winter. Lakes Vanda, Bonney and Fryxell are covered with ice sheet of 3–5m thickness all the year round. An intermediate type of saline lake is known in the Vestfold Hills, Princess Elizabeth Land, in which the surface is covered with ice in winter and open in summer. Table 6 summarizes the grouping of saline lakes in Antarctica according to the surface conditions.

On evaporation, the deuterium is apt to be concentrated in water relatively to vapour. In contrast, the deuterium in ice is apt to be concentrated relatively to water on freezing. Thus, a saline water formed by normal temperature evaporation will be rich in deuterium, and *vice versa*, under frigid conditions. The Dead Sea water collected by one of the authors (YAMAGATA) on June 2, 1964 in the vicinity of Sodom, Israel gave a deuterium content of ⊤8.0 SMOW (it is +6.1 the city water of Tokyo). This is quite in contrast with large minus values the saline waters of Antarctica (Table 2), indicating the presence of a mechanism of concen-

Table 6 Grouping of Antarctic lakes according to the surface conditions

Group	Lakes	Surface conditions
I	Don Juan Pond, Victoria Land	Do not freeze all the year
II	Deep Lake, Club Lake, Princess Elizabeth Land	Partly freeze in winter
III	Lake Dingle, Lake Stinear, Princess Elizabeth Land	Freeze over during July–November
IV	Lake Vanda, Lake Bonney, Lake Fryxell, Victoria Land	Ice-covered all the year

*Table 7. Sequential changes and local variation in the chemical composition
and specific gravity of saline waters in Don Juan Pond.*

Time of collection	NaCl (Eq. %)	KCl (Eq. %)	MgCl$_2$ (Eq. %)	CaCl$_2$ (Eq. %)	Specific (gravity)
Oct 1961*	7. 95	0 065	1 57	90 42	1. 251
Dec 1962	2. 75	0.058	2. 30	94 89	1.351
Dec 1963	1 38	0 086	3. 12	95. 42	1 380
Dec 1964					
D1	0. 95	0 092	1. 96	96.99	
D2	1. 27	0.096	1 92	96. 70	
D3	2 99	0.099	2 15	94. 77	
D8	1 00	0 096	2. 07	96.83	

* MEYER *et al.*, 1962.
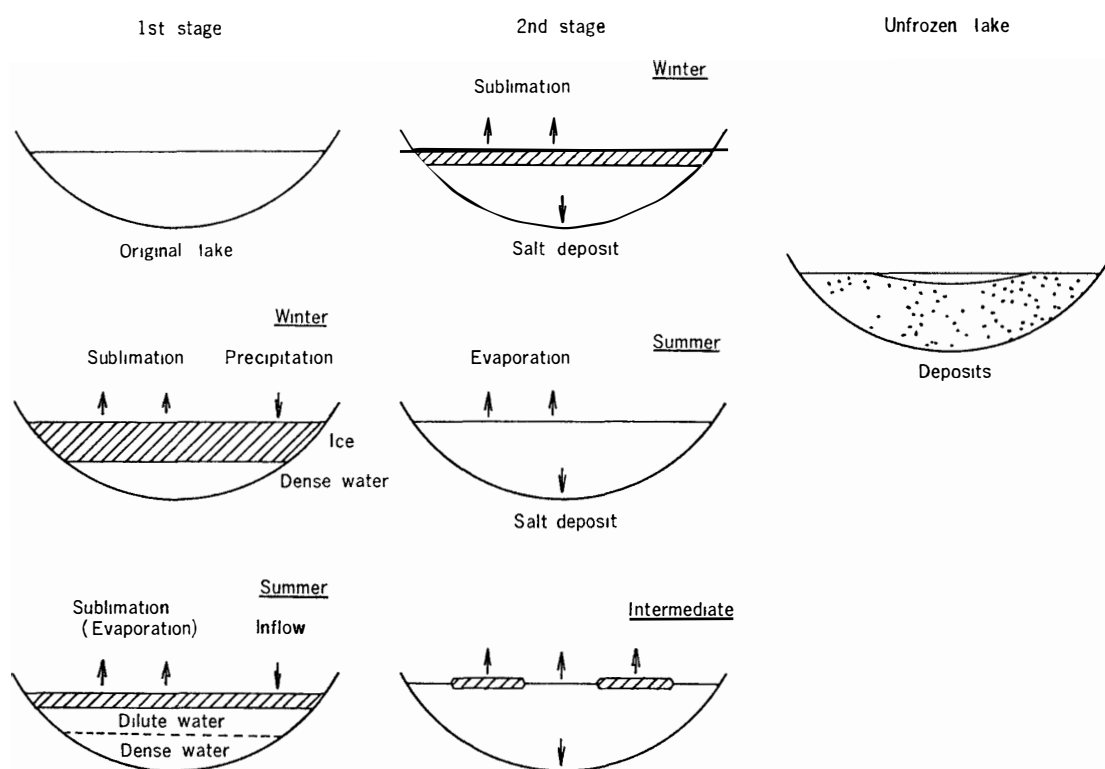
Fig. 2. Scheme of the formation of unfrozen pond.

tration under frigid conditions (Fig. 2).

5. Don Juan Pond

Don Juan Pond was discovered by a U.S. Navy helicopter on October 11, 1961
and was named by MEYER *et al.* (1962). It is located in the south fork of the
Wright Valley at lat. 77°34′S and long. 161°10′E. It is nearly in the center of the

flat plain surrounded by moraine heaps and talus deposits at the end of the Valley (Photo 2). In December 1963, the pond was about 300m long (east-west) and 100m wide (north-south), the depth being only 10cm. The values are in contrast with the description by MEYER *et al.* (1962) who measured 700m long, 200m wide, and 11cm deep in the summer of 1961–62.

Antarcticite, a new mineral calcium chloride hexahydrate ($CaCl_2 \cdot 6H_2O$) was found in the pond (Photo 3) and was reported previously by TORII and OSSAKA (1965) Crystals of halite (NaCl) were also found adhered to the rocks in the pond. The water is saturated with calcium chloride and sodium chloride, and showed sequential changes in the chemical composition as shown in Table 7. Data for October 1961 were taken from the work by MEYER *et al.* (1962) and the sample for December 1962 was supplied by Dr. H. FUKUSHIMA, Yokohama Municipal University.

Sequential increase in the specific gravity indicates that the concentration process was going on since the summer of 1961-62 and by this the contradiction in the magnitude of the pond between 1961–62 and 1963–64 as mentioned above can be explained. Table 7 also suggests a relatively large deposition of sodium chloride to calcium chloride. As the result, per cent contents of the chlorides of potassium, magnesium and calcium increased year by year. Sulfate ion could not be detected in the water.

Table 8 shows the soluble chemical components of the deposits in the basin of Don Juan Pond. The deposits were taken at localities indicated in Fig. 3 in the vicinity of the camp. The samples differed in proportion of soluble material. The soluble salt in Nos. D, E and F is sodium chloride ($>97\%$) with small amounts of calcium chloride and/or sulfate, while No. G contains a large proportion of calcium chloride (89%). Nos. F and K are characteristic in containing several per cent of sulfate, with magnesium in the latter Discussion on the deposits will be made

Table 8   Soluble chemical components of the deposits in flat basin of Don Juan Pond

| Locality No	Insoluble %	Eq % in soluble portion					
		Na	K	Ca	Mg	Cl *	SO₄ *
D	27 3	97 5	0 029	2 3	0 029	98 8	1 2
E	27 5	98 1	0 023	1 9	0 040	99 2	0 8
F	67 9	91.5	0 18	8 2	0 16	94 0	6 0
G	86 6	8 92	0 43	88 8	0 18	100 0	0 0
H	80 2	96 6	0 064	3 3	0 053	99 5	0 5
K	54 9	78 2	0 035	21 3	0 49	97 5	2 5

* Carbonate was not determined

Photo 1 Carcass of crab-eater seal found in the vicinity of Don Juan Pond, Wright Valley
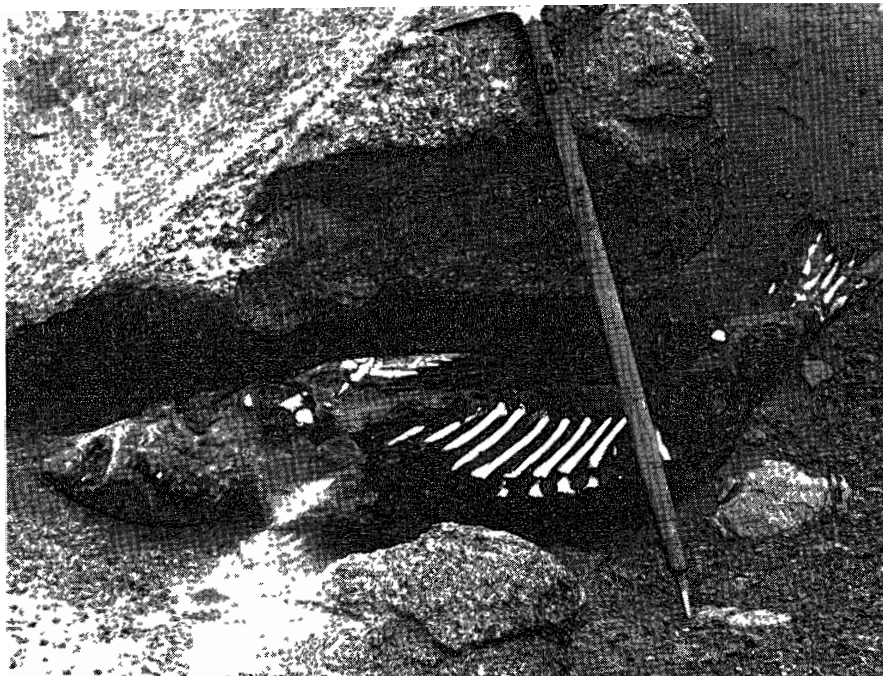
Photo 2 Don Juan Pond and its basin viewed from east to west White arc in the low center indicates salt deposits on the ground, and dark ellipsoid moraine heap on the background
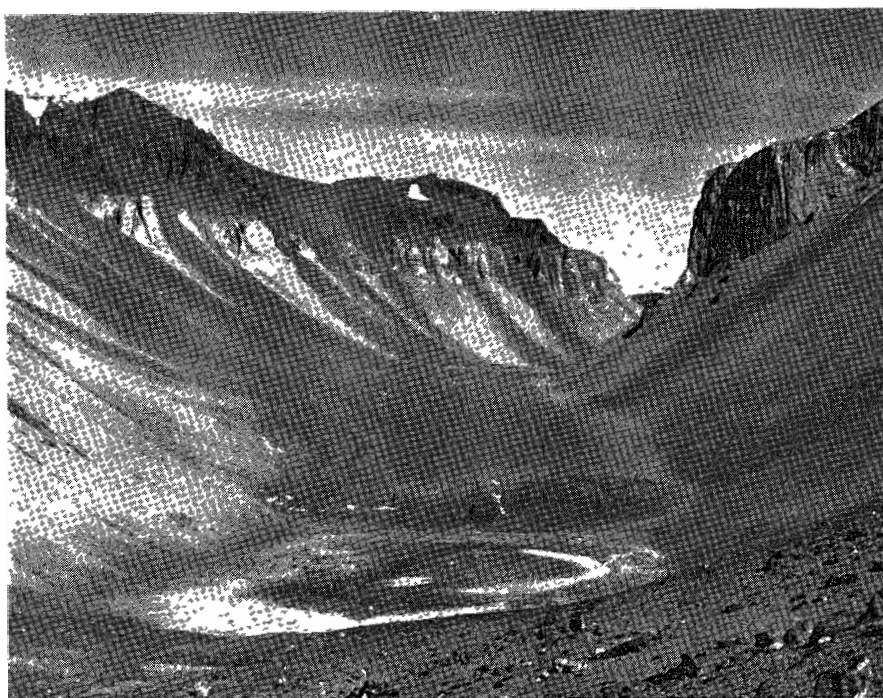
Photo 3 Crystals of Antarcticite, $CaCl_2 \cdot 6H_2O$, a new mineral found in the water of Don Juan Pond
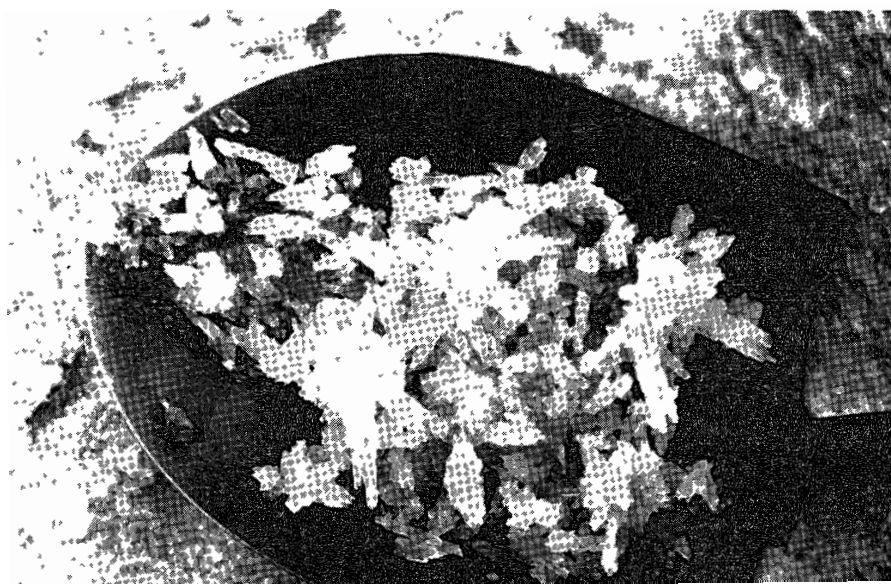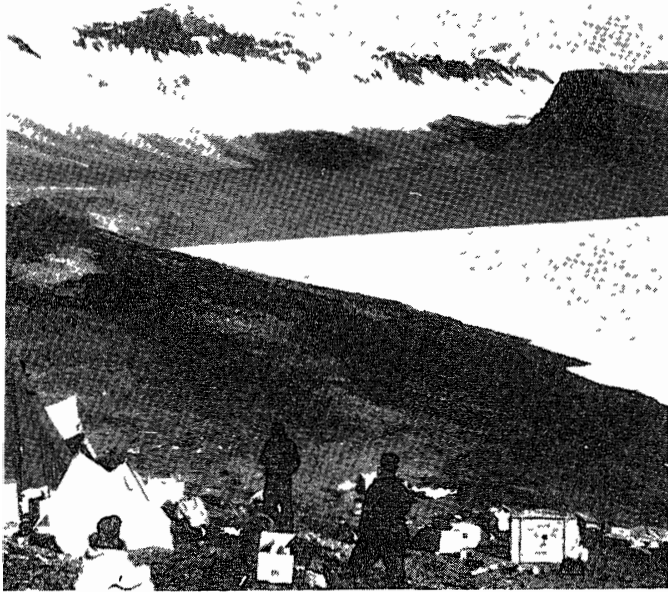
Photo 4　Lake Vanda, Wright Valley and a camp of the New Zealand party on the south shore

Photo 5　Drilling on Lake Vanda by use of a SYPRE's ice-auger

Photo 6　West end of Lake Bonney, Taylor Valley, showing rough surfaces of the lake and the terminal of Taylor Glacier
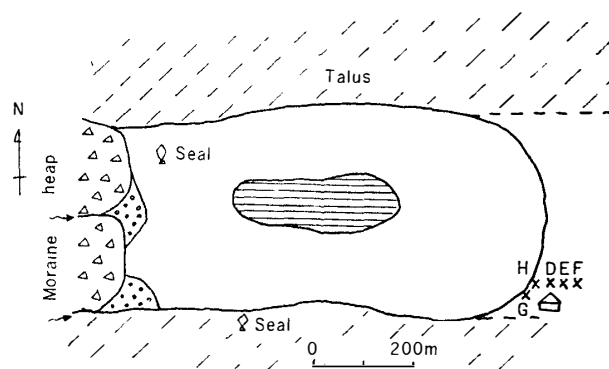
Fig. 3. Don Juan Pond

Table 9. Chemical analyses of waters around Don Juan Pond.

Site	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Cl (mg/kg)	SO₄ (mg/kg)
Inflow to Don Juan Pond						
D7	2 1	36	26.3	18 5	61 1	52.9
D6	6 5	65	527 9	44.2	1,090	80 5
South Fork						
No 1 Red Pond	11	119	94 8	44.2	228	219
No. 2 White Pond	37.2	1,270	75 6	325 3	2,299	178
No 3 Ice Pond	1.0	8	5 1	1 4	18.6	6.4

in a separate paper.

The results of chemical analysis of land waters in the vicinity of Don Juan Pond are tabulated in Table 9.

6. Lake Vanda

Lake Vanda is situated in the Wright Valley (lat. 77°32′S and long. 161°30′E) about 47 km from the coast. It is about 7 km east-west and 2 km north-south, at the height of 95m above the sea level. The surface is covered with ice sheet 4m thick in summer. An inflow (Onyx River) was observed in the summer of 1964–65 and a flow rate of about 60 *l*/sec was measured, but the lake had no outlet (Photo 4).

The characteristics of the lake revealed by several investigators (see 1. Introduction) are summarized as follows: (1) High temperatures (up to about 25°C). (2) The presence of dense waters at the bottom (chlorinity is up to 4 times that of sea water). The data for (1) were previously reported (TORII, YAMAGATA and CHO, 1967).

The lake water is chemically stratified with two major layers (Figs. 4 and 5 and Table 10). Another minor layer with the smallest salinity ($<$100mg Cl/kg) lies just underneath the ice sheet which is probably originated from ice melt. Increase in the salinity begins somewhere between 40 and 50 m and the highest chloride contents were 75.88 g/kg at V6 (65m) in December 1964 and 72 04 g/kg at V5 (65m) in December 1965.

The chemocline approximately coincides with thermoclines which begin at about 40m, with the maximum at about 50m. The deep saline layer seems to be stable in holes V5, 6, 9 and 10 (Fig. 6) because the increase in density compensates the expansion caused by temperature increase. In holes V1, 2 and 3, in contrast, the water mass seems to be unstable because the chlorinity increases only a little toward the bottom (Fig. 7). The water masses with eventually increasing chlorinity as shown in Figs. 4 and 5 should have been caused by upward motion and mixing of underlying denser water.

The horizontal distribution of dense water is not uniform in contrast with the surprisingly uniform distribution of water temperature. This may suggest independency between the temperature and the salinity The temperature-salinity diagram which is commonly used in water-mass analysis was attempted but it failed to suggest the presence of dependency.

These observations and the absence of a thermal dome (TORII et al., 1967) centering somewhere around the deepest place as reported by ANGINO et al. (1965) may exclude the postulation of inflow of thermal springs as the source of salt and heat

Several possible sources of the salts have been postulated and the chemical composition of water is thought to be one of the keys to solve the problem. However, it should be borne in mind that the present composition does not necessarily represent a primordial composition. Thus, even if the ratio of two elements in lake water was not consistent with that in sea water, we should not exclude sea
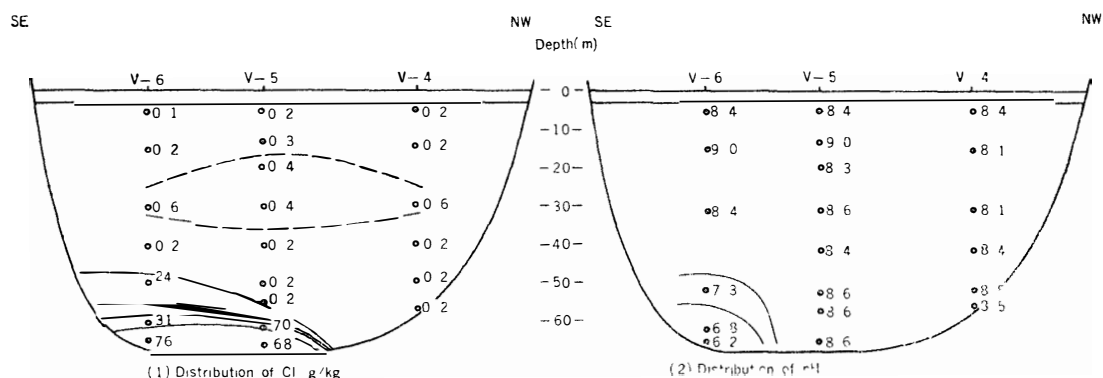

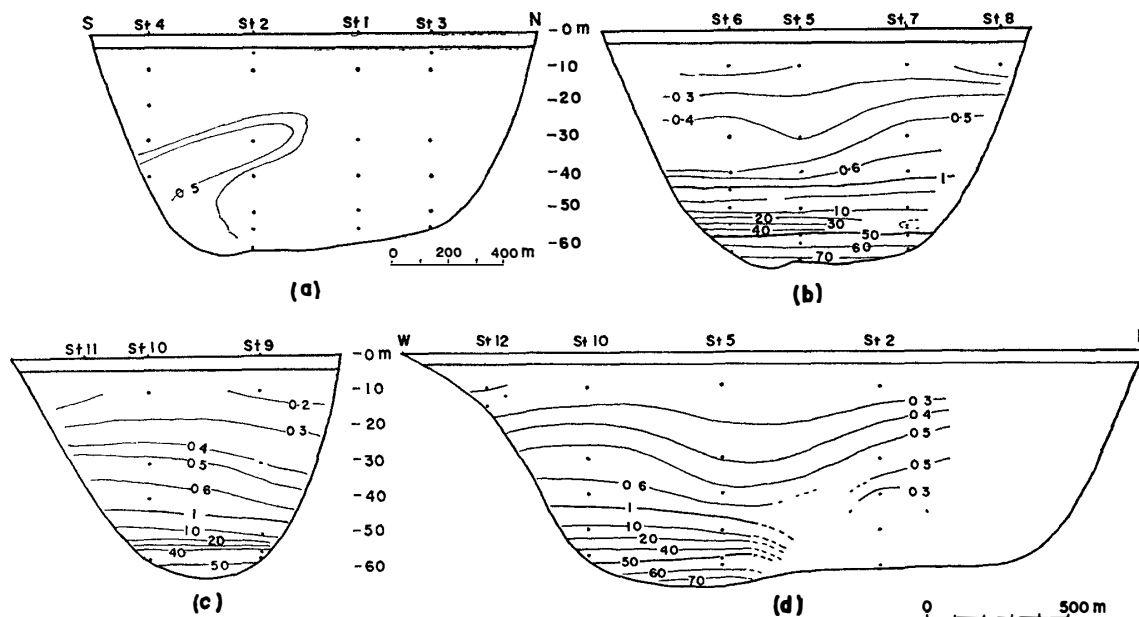Fig 4   Chlorinity and pH stratification in Lake Vanda, January 2-3, 1965

Fig. 5.   Chlorinity (g/kg) stratification in Lake Vanda.

water as the source of salts, because the elimination of sulfate ion, for example in the pair of sulfate: chloride, from the water might have occurred in the process of concentration.

Likewise, the present water (H_2O) does not always represent a primordial water, because sublimation and evaporation should have taken place together with fresh supply of precipitation. Thus, inconsistency in deuterium content between the present water and sea water could not be taken as the reason for excluding sea water as the source of salts. In conclusion, the source of salts should be considered separately from the source of water.

Field measurements of some minor constituents of water were made. Table 11 summarizes the results. Statistical analysis gave a correlation factor of +0.94 between chloride and silicate, indicating a close interrelationship, but those for chlo-

Table 10.   Chemical analyses of waters in and around Lake Vanda,
concentration in mg/kg (January 1965)

Site	Depth (m)	pH	Na	K	Mg	Ca	Cl	SO$_4$
Onyx Pond	0	7.4	9	3.3	3.8	14.4	21.5	9.7
Inflow	0	7.4	9	2.9	3.2	13.3	19.6	9.1
V1	3.7	8.0	13	5.4	6.2	23.8	78.6	5.1
	5	–	20	8 9	10.3	41.7	135	11
	9	8.2	35	13.0	14.3	59.0	188	12
V2	3.75	8.3	12	5.3	3.9	17.0	76.3	5.4
	5	8.3	21	8.3	9.0	38.5	127	8.2

| Site	Depth (m)	pH	Na	K	Mg	Ca	Cl	SO$_4$
V2	13.5	8 3	39	15 8	14.9	60 6	256	16
	15 5	7.9	66	27 4	35.5	141	525	24
	32 5	7 8	36	13 4	43 0	173	209	24
V3	3 5	7.3	8	4 3	3 0	14 4	49. 3	2 5
	5	8 4	28	11 2	12 9	52 9	172	15
	13 5	8 3	44	18 4	20 5	100 5	305	18
	15 5	8.2	66	25 7	18.8	76 4	480	22
	20	8 5	32	12 8	16 3	62 6	205	17
	31 5	8 6	32	13 2	15.5	63 3	205	16
	38	8 2	67	26.4	39 2	167	517	22
	42	8 6	40	13 9	16 0	63 9	206	15
	45	8 5	34	12 9	14 9	61.1	196	13
	57	8.4	35	14 3	16 7	69.4	221	14
	63	8 4	33	14 4	15.7	64 2	206	17
V4	3.4	7 6	12	5 3	5 3	21 5	71 7	5. 1
	5	8.4	35	13.4	15 7	60 8	198	14
	15 5	8.1	36	13.1	15.0	62 3	199	15
	31 5	8 1	76	32 4	45.7	184	578	24
	42	8 4	40	13 7	16 8	65. 1	211	17
	52	8 5	34	13.3	15.2	61.0	198	13
	57	8 5	38	13.4	16. 1	64.1	206	15
V5	3.5	8 0	15	7 0	6.3	27.9	90. 0	7 4
	5	8 4	36	13.4	14.9	61 7	197	16
	13 5	9 0	41	17 0	21.0	88.3	278	18
	20	8 3	48	21.9	28.8	118	370	20
	31.5	8 6	55	24 0	32.9	128	404	21
	42	8 4	36	13.8	16 8	66 2	211	16
	52 5	8.6	36	13.6	16 3	64.5	209	18
	57	8.6	33	13 2	16 8	66. 3	213	16
	62	8.6	4, 595	1,057	7, 155	23,080	70, 280	592
	65.5	8 6	4, 149	1,014	6, 923	22, 370	68, 160	596
V6	3 6	7.1	2	1 8	1 7	6.4	21.4	2 2
	5	8.4	19	7. 2	8.5	32.7	105	10
	15 5	9 0	34	13.4	15 8	66.1	210	17
	31 5	8.4	64	28 8	44 3	184	573	24
	42	–	33	13.0	30.8	123	199	16
	52	7 3	1,655	406	2,329	7,918	23,650	187
	63 5	6 8	1,794	419	3,137	10,120	30,680	288
	66 5	6.2	4,570	960	7,580	24,620	75,880	622
V7	3 6	8.6	32	12.6	14 6	57 8	185	14. 4
	5	8.6	35	13 7	17 1	60.3	201	16
	15.5	8 6	38	14.0	16.9	67.0	217	16
	31.5	8.4	33	14 0	16.0	63.7	207	17
	42	7.9	33	13.1	14.9	59 8	192	16
	52	6.6	1,460	438	2,081	7,132	21,250	137
	56	6 7	2,390	502	4,012	13,250	39,570	255
	61	6.2	3,828	905	6,395	20,850	62,940	448
V8	3.5		9	4 2	5.3	20 9	68.8	2.9
	5		32	13.0	14.8	58.1	189	14
	15.5		66	27 9	38.0	155	485	21
	20		68	32 2	45.2	184	572	21
	31 5		63	29.4	40 9	171	529	21
	42		90	38. 3	75 1	297	911	26
	52		1,460	394	2,242	7,546	22,610	177
	59		2,820	597	5,390	17,510	52,490	450
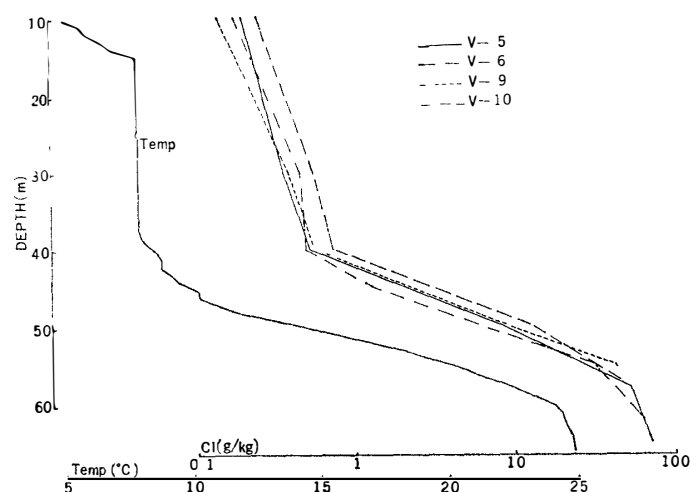
Fig 6.   Chloride content vs. temperature in Lake Vanda,
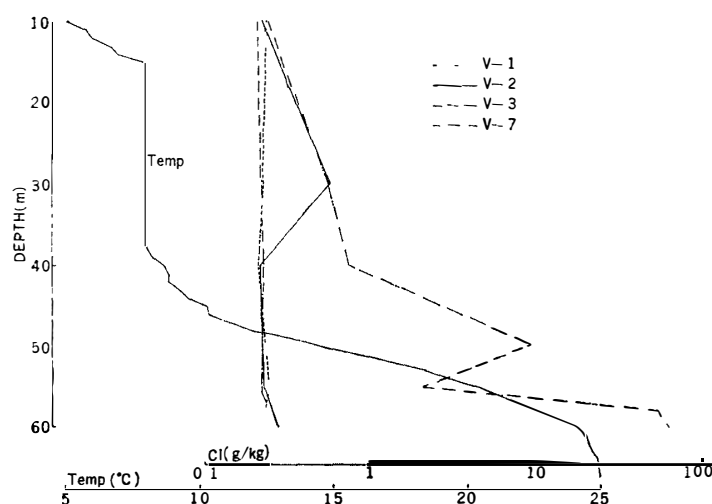December 1965, showing stable condition.

Fig. 7.   Chloride content vs. temperature in Lake Vanda,
December 1965, showing unstable condition.

ride-phosphate and chloride-nitrite were +0.49 and −0.22 respectively, suggesting a different mechanism of distribution, especially of the nitrite ion, probably in relation to some biological activities.

7. Lake Bonney

Lake Bonney is situated in the Taylor Valley (lat. 77°43′S and long. 162°23′E) about 26 km away from the coast, extending about 5 km east-west and 1 km north-south, at the height of 56 m above the sea level. The lake is composed of two lobes, east and west, which are connected by a channel about 40m wide and 11m deep. The surface is covered with ice sheet about 4 m thick in summer. A considerable amount of melt-water is supplied in summer from both sides of the lake,

Table 11   Silicate, nitrite, phosphate and chloride contents of waters
in Lake Vanda (December 1965)

Hole No.	Depth (m)	pH	Cl (mg/kg)	Silicate -Si (mg/l)	Nitrite -N (µg/l)	Phosphate -P (µg/l)
V1	10	8 5	240	2.67	6 7	0 16
	30	8 5	228	2 63	4 3	0 37
	40	8.5	224	2.56	3.9	0.22
	50	8 5	230	2 63	4.2	0 59
	55	–	245	–	–	–
	59	8 5	230	2 63	3 9	0 16
V2	5	–	201	1 97	4.3	1.49
	10	8 55	223	2 49	4 2	0 16
	30	8.1	570	5 20	4.3	0.16
	40	8 4	217	2 63	4 3	0 16
	50	8.4	230	2 56	4 3	0 16
	55	8.4	229	2 63	5.7	0 16
	60	8 2	279	2 61	5 0	0 12
	bottom	–	174	–	5 0	–
V3	4	–	137	1 77	4 3	0 34
	10	8 5	211	2 67	2 1	0 16
	30	8 5	222	2 67	4.3	0 16
	40	8 5	225	2.67	4.3	0 16
	50	8.4	226	2.61	4 2	0 16
	56	–	224	–	–	–
	57	8 2	237	2 71	4.2	0 16
V4	10	8 5	238	2 75	2 1	0 03
	20	8.6	223	5 56	2.1	0 12
	30	8 6	217	2.58	2.1	–
	39	8 1	555	2.98	4 3	1.24
V5	10	8 0	203	2.05	2.1	0 25
	30	7 9	385	5 31	4.8	0 03
	40	7 9	529	4.77	2 1	0 16
	50	7.3	8,656	6 46	11.2	–
	58	–	53,190	–	0 7	–
	60*	6 5	57,430	–	–	–
	65**	6 4	72,040	–	–	–
V6	10	8 1	183	1.97	4 2	0 74
	30	7 9	471	3 47	4 2	0 56
	40	7 9	502	3 54	4.3	0.37
	45	7 7	1,355	5 87	–	0.03
	50	7 4	6,310	5 39	7.8	0 16
	55	7.0	31,930	9.41	5 0	–
	60***	6 6	52,980	–	–	–
	62	–	65,480	–	–	–
V7	10	8 4	245	2.83	2 1	0 12
	30	8 2	555	4 92	2.1	0 31
	40	8 1	742	5. 79	2.1	0 22
	50	7 9	9,448	6 18	28 0	0 50
	55	7 7	2,136	4 58	4 3	0 16
	58****	7 1	55,380	10 1	3 5	–
	60	–	63,550	–	–	–
V8	10	8 45	161	2.27	2 1	0 16
	20	8 4	423	3.54	2 1	0 25
V9	10	8 3	145	1.98	–	1 30
	30	8 1	395	5 17	2.1	0 37
	40	7 9	572	5.84	5 5	0.16

Hole No.	Depth (m)	pH	Cl (mg/kg)	Silicate -Si (mg/l)	Nitrite -N (μg/l)	Phosphate -P (μg/l)
V9	50	6 9	9,331	7.33	35.0	0 84
	55	6.9	43,800	9.41	–	–
	56	6 7	47,080	–	–	–
V10	10	8 4	252	2.72	4.2	0.31
	30	8.1	560	5.59	2.5	0.16
	40	7.9	747	5.70	3.5	0.37
	50	7.2	13,030	7.36	43.4	–
	57	6.6	46,330	9.41	2.5	–
V11	10	8.1	175	1.57	4.3	0 16
	30	8.0	527	3.60	4.3	0.06
V12	10	8.0	186	1.34	2.1	0 37
	15	7 8	254	3.55	2.0	0.12

H_2S contents in mg/l . * 1.53　　** 27 4,　　*** 1.36,　　**** 3.40

by Taylor and Rhone Glaciers in the west and Sollas Glacier in the east, but the lake has no outlet (Photo 6).

Table 12 summarizes the chemical composition of the waters from each lobe and the channel. The highest chloride content was 154.5 g/kg in the bottom water (32m) in the east lobe. Total amount of dissolved solids can be calculated as 271.9 g/kg or 326 g/l by summing up the main components; this is a little more than 9 times the salinity of sea water. The principal components are sodium and magnesium chloride, accounting for about 95% of dissolved solids in the east lobe water. There can be found a difference in chemical composition between the east and the west lobes (Table 13). Equivalent ratio Na:Mg is 1:2 in the former and the ratio is reversed in the latter and the channel. It should also be noted that the relative contents of calcium and sulfate are larger by factor of 2-3 than in the east lobe.

The chemocline in the east lobe roughly coincides with the layer of maximum
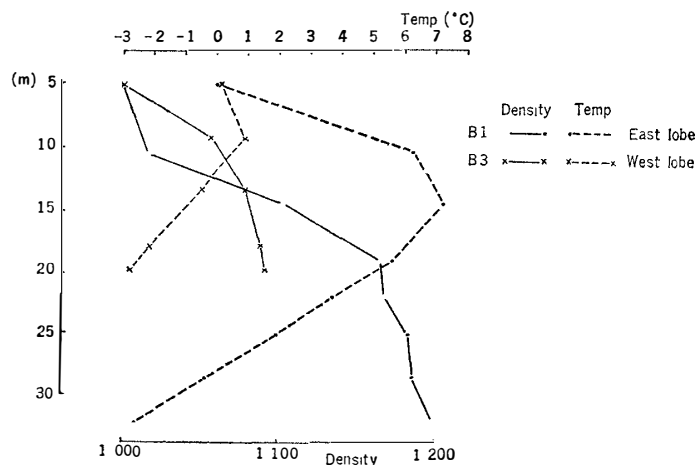

Fig. 8. Density vs. temperature in Lake Bonney, January 1965.

Table 12. *Chemical analyses of waters in and around Lake Bonney (January 1965).*

Site	Depth (m)	Specific gravity	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Cl (mg/kg)	SO$_4$ (mg/kg)
Taylor Glacier inflow		1.000	1.9	9	30.6	2.9	20.4	51.2
B1, East lobe	5	1 0005	25.6	335	74 4	64.4	734	160
	10.5	1.0156	417	3,920	343	1,762	12,420	473
	14.5	1.1034	1,540	16,780	1,260	16,700	82,470	2,480
	19	1.1636	2,950	33,300	1,430	25,470	129,700	2,560
	22	1.1665	2,750	32,600	1,430	25,290	131,600	2,480
	25	1 1819	3,730	38,800	1,600	27,270	142,800	2,710
	28 5	1 1839	3,090	33,900	1,810	26,970	144,500	2,760
	32	1.1983	2,870	36,000	1,540	26,030	154,500	2,950
B4, East lobe	5	1.0008	18.7	215	52 4	45.3	520	106
	10 5	1.0117	269	3,170	298	1,275	9,436	367
	14.5	1.1027	1,680	18,100	1,260	16,470	81,940	2,480
	19	1 1636	2,850	27,200	1,540	25,340	129,700	2,640
	22	1.1715	3,060	30,900	1,510	25,970	135,800	2,630
	25	1.1816	3,120	−	1,620	26,900	142,900	2,760
	28.5	1.1865	3,300	34,300	1,560	27,100	146,300	2,830
	32	1 1979	6,861	80,000	1,440	26,140	154,500	2,960
B2, Channel	5	1.0017	45.0	445	96 1	90 2	1,005	196
	8.5	1.0490	602	14,500	1,510	4,087	36,780	3,320
	10.7	1 0707	1,030	20,700	2,140	5,461	53,040	4,250
B3, West lobe	5	1.0010	21 0	280	62 2	53.8	634.8	133
	9.5	1.0545	716	16,300	1,660	2,420	40,680	3,290
	13.5	1 0776	1,980	46,900	2,270	6,065	58,960	4,530
	18	1.0871	1,240	33,100	2,200	7,115	66,820	4,290
	20	1 0901	1,410	22,700	2,160	7,472	69,360	4,190

Table 13. *Difference of chemical composition of the saline waters in east and west lobes of Lake Bonney (Eq % or ratio)*

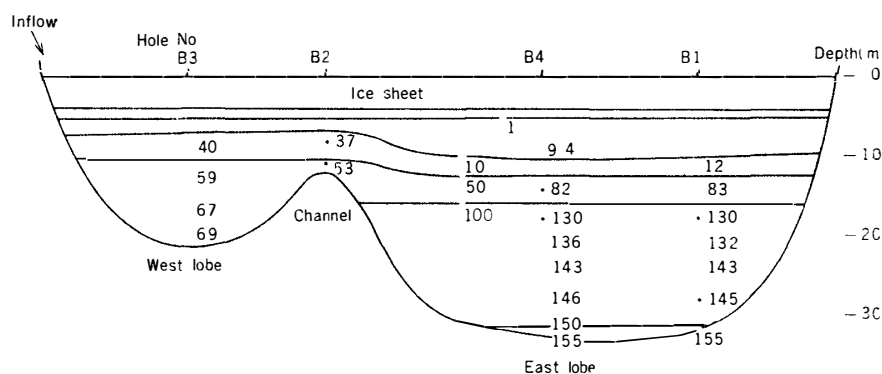| Hole No. Depth (m)	Na	K	Ca	Mg	SO$_4$/Cl	Cl (g/kg)
East lobe						
B1　14	33.10	1 79	2 85	62 27	0.0222	82 47
B4　14	35.04	1.91	2 80	60.26	0 0224	81 94
Channel						
B2　11	60.71	1.78	7 21	30.30	0 0591	53 04
West lobe						
B3　20	56.58	2.07	6 17	35.15	0.0446	69.36

Fig. 9. Chemical stratification in Lake Bonney, January 1965.

temperatures which extends around the depth of 15m as shown in the density vs. temperature diagram (Fig. 8). Stability of the saline layer seems to be higher than in Lake Vanda, as the temperature decreases with depth below 15m; this is not the case in the west lobe. Chemical stratification as represented by the chloride content is shown in Fig. 9. There can be found a break of isochlorinity curves near the channel, suggesting the presence of some exchange or diffusion of dissolved matter between the lobes; this same pattern is found also in isotherms as

Table 14. Silicate, nitrite, phosphate and chloride contents of waters
in Lake Bonney (December 1965).

Hole No.	Depth (m)	pH	Cl (mg/kg)	Silicate -Si (mg/l)	Nitrite -N (μg/l)	Phosphate -P (μg/l)
B1	5	8 0	351	0.37	4.2	0 37
	10	7.6	5,445	1.91	7.3	0 50
	14	7.0	63,040	3 41	70	0.34
	21	7 2	116,700	2.28	312	0.47
	28	6.9	136,400	2.19	308	0 47
	32	6 7	147,800	1.99	270	–
B2	5	8 4	1,116	1.95	7.6	0.31
	7.5	7 7	4,140	1 24	5.3	0 53
B3	5	8 4	827	0 44	5.3	0.43
	8	7 3	9,902	1.25	4 3	0.50
B4	5	8 4	455	0 43	5.5	0 43
	9	7 0	29,040	2.32	4 3	0.68
	14	6 8	51,370	0.73	1.7	0.62
	21	6 6	58,670	0 10	5.2	0.68
	28	6 4	77,930	0 06	9 8	0 62

shown in the previous report (Torii, Yamagata and Cho, 1967). Heat exchange is also possible.

Halite (NaCl) and gypsum ($CaSO_4 \cdot 2H_2O$) were identified in the bottom sediments of the lake, but a detailed description will be made later in a separate publication.

Field measurements of some minor constituents of water were made. Table 14 summarizes the results for silicate, nitrite and phosphate. The high silicate contents were observed at the chemocline, 10–15m (2–3 ppm Si). Discrepancies in the silicate and nitrite contents between B1 and B4 are striking. The extraordinarily large content of nitrite in the deeper water at B1, amounting to about 0.3 mg-N/l, is noticeable and a similar local high concentration found in Lake Vanda (Table 11) should be also taken into consideration for explanation.

8. Lake Fryxell

Lake Fryxell is situated in the Taylor Valley (lat. 77°36′S and long. 163°08′E) about 6.5 km from the coast, extending about 5 km southwest – northeast and 2 km northwest – southeast, at the height of 12 m above the sea level. The surface is covered with ice sheet about 2 m thick in summer. The lake is surrounded by the Canada and Commonwealth Glaciers and a considerable amount of inflow was observed in summertime.

Table 15   Chemical analyses of waters in Lake Fryxell (January 1965)

Hole No	Depth (m)	K (mg/kg)	Na (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	Cl (mg/kg)	SO$_4$ (mg/kg)
F1	5	19 8	200	25 8	20 1	250	25 7
	9	125	1,540	109	165 1	1,917	169
	13	198	2,600	148	298 7	3,390	230
	16	213	2,350	62 8	337.1	3,766	175
F1–2	6	41 9	399	49 2	42 6	512 2	53 9
	8	108	1,140	101	139 4	1,638	157
	10*	166	1,980	116	215 0	2,454	218
	12	190	2,540	119	263 5	2,992	249
	14**	205	2,180	145	300 3	3,414	229
	15 3***	209	2,480	149	322 5	3,615	200
F2	5	10 9	46	14.0	10 4	130	13 3
	8+	–	–	63 3	83 1	968	88 6
	11+	–	–	88 5	138 7	1,591	140

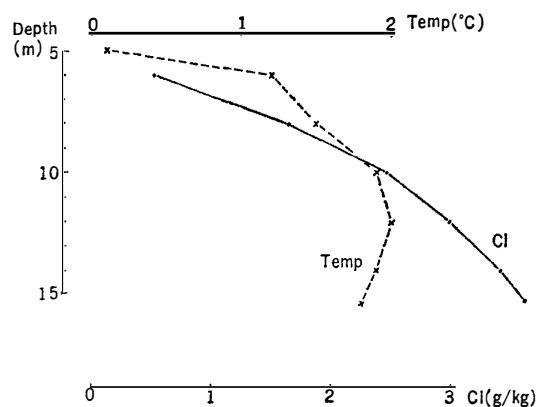H_2S (mg/kg)　* 5 6,　** 7 7,　*** 13.4,　+ 0

Fig. 10. Chloride content vs. temperature in Lake Fryxell (F1) (January 1965).
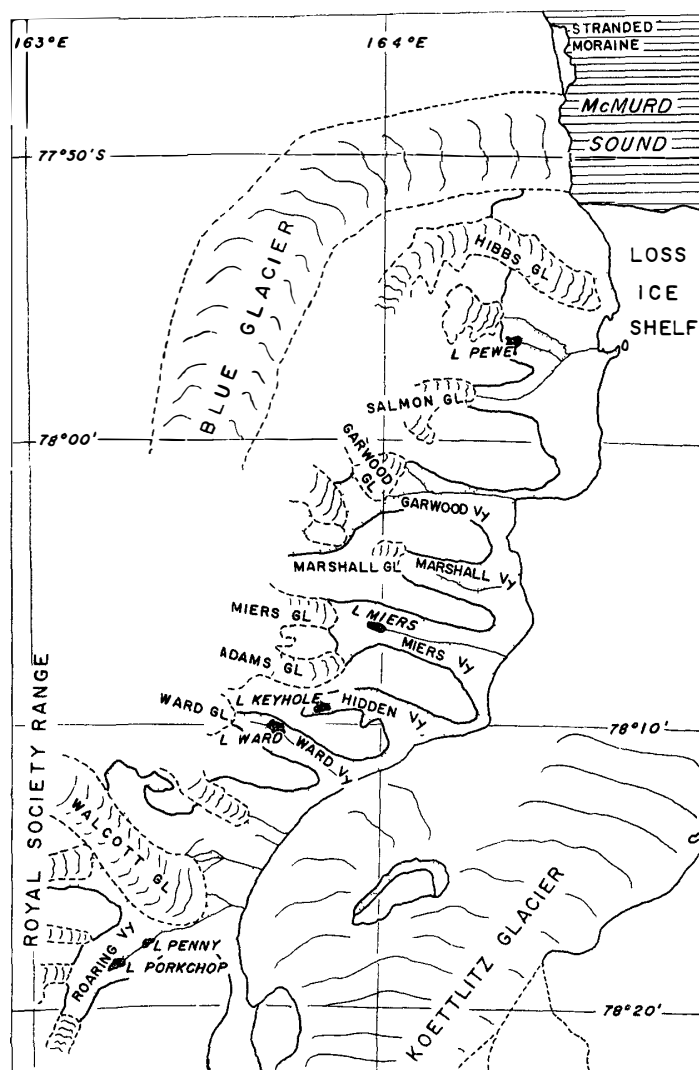

Fig. 11. Locality of fresh water lakes in Victoria Land.

Table 16. Chemical analyses of fresh water lakes

	Na (mg/l)	K (mg/l)	Ca (mg/l)	Mg (mg/l)	Cl (mg/l)	SO₄ (mg/l)
Lake Porkchop	5	2 7	7 7	2 6	5 6	12 7
Lake Penny	12	6 7	20 2	2 7	25 6	19 8
Lake Ward	5	2 3	10 4	1 4	11 9	11 9
Lake Ward inflow	7	2 2	9 9	1 4	11 9	11 1
Marshall	24	4 2	13 2	1 6	14 4	39 5
Lake Péwé	–	–	7 9	0 6	5 5	6 5

Chemical composition of the water is shown in Table 15 for three holes drilled in January 1965. The largest salinity was found in Fl at the depth of 16 m, indicating the total dissolved matter of about 7 g/kg; this is one-fifth of that in sea water. The ionic composition is similar to sea water in contrast to other lakes under investigation. One of the main characteristic chemical features of Lake Fryxell is the presence of hydrogen sulfide in deeper waters. The pattern of chemical stratification for hole Fl' is shown in Fig. 10 in comparison with the temperature profile.

9. Other Lakes

Pertinent data for other lakes to which short visits were made (Fig. 11) are presented in Table 16. All of these are fresh water lakes.

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