Salt Balance in the Don Juan Basin

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ドンファン湖盆の塩収支

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要旨：1961年10月に発見されたビクトリアランドの不凍池ドンファンについて，1963年から1976年までの15シーズンにわたる観測と，DVDP 13コア試料の研究結果から，池水の経年変化，池周辺にみられる塩類堆積物中の2次鉱物，それにコア試料の分析結果を示した．以上の研究結果から，ドンファン湖盆の塩収支，水収支について考察を試みた．

　古湖水の存在を仮定すると，その湖水量は旧湖岸線を 20 m とすれば 1.2×10^7 m³ となり，また湖盆に推定される塩類の存在量からは 2.6×10^7 m³ となり，ほぼ同一のオーダーであることがわかった．この塩類の収支試算，現在池中に流入する氷河融水量，それに池水の年間蒸発量などに基づいて，古湖水が現在に至るまで濃縮されるに要した年数をみると，300〜400 年という結果をえた．

Abstract : On the basis of the information obtained in the reconnaissance conducted since 1963 around Don Juan Pond together with the results of the DVDP core analysis, the salt and water balances in the Don Juan basin are discussed. The sequential changes of pond water characteristics for the period 1961–1976, and the description of evaporites in and around the pond are given. Assuming the presence of a paleolake, the volume of the lake was estimated as 1.2×10^7 m³ from the paleolake shoreline or 2.6×10^7 m³ from the salt deposits inventory. A water balance model applied to this paleolake, based on the measured inflow and evaporation rates, has resulted in an estimate of 100 years order of magnitude for the time required for the formation of the present pond.

1.　Introduction

The only pond known to possess the new mineral now called "antarcticite" (TORII and OSSAKA, 1965) was discovered by a VX-6 helicopter in 1961 and

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was given the name "Don Juan" after the first name of the pilots Donald ROE and John HICKEY (MEYER *et al.*, 1962). The pond is situated in the south fork of the Wright Valley, Victoria Land, about 13 km west of Lake Vanda. It has no outflow, but is supplied with melt water from the Wright Upper Glacier on the west for about 70 days in midsummer. The size of the pond varies considerably from year to year due to the change in water supply, but the salt content is the highest among the Antarctic saline lakes.

Of all the saline lakes in the Dry Valleys, the authors have been particularly attracted to this pond since 1963 when Japanese summer geochemical field party visited there first and in the course of continuing investigations, became convinced of the need to drill down to basement rock in order to clarify the geochemical processes in the formation of the entire basin. Using some of the results from the DVDP core samples, as well as the information obtained since as far back as 1963, an outline of the knowledge we obtained on the salt balance in this basin is given.

2. Sequential Changes of the Pond Water

H. FUKUSHIMA, the first Japanese biologist who visited the pond in 1962, brought one liter of water sample back to this country and since then, our research of the sequential changes in the chemical composition was started. These observations were conducted every year except for the two seasons between 1966–68 during which one of the authors (TORII) wintered over at Syowa Station situated about 3,200 km away from the pond. The sequential changes during 15 years are shown in Table 1, and Fig. 1 shows a rough sketch of the variation of the main components in the pond. Beginning with calcium chloride, a maximum concentration was observed in the 1964–65 summer. Since then, there has been a gradual decrease except for a peak in the 1972–73 summer. The 1970–71 summer is known to have had excessive runoff resulting in a rise of the water level of Lake Vanda by two meters. In this season, inflow into Don Juan Pond also increased and the maximum water depth recorded was 25 cm in contrast to about 10 cm in ordinary summer. Changes in the water supply are reflected by changes in the concentration of calcium chloride in the pond water, but the ratio of calcium to chloride is comparatively constant, showing a value between 0.50–0.55.

Fig. 2 shows the relationship between the calcium and sodium concentrations in the pond water. Each dot represents their concentrations in particular summer seasons. The numeral 61, for example, means the 1961–62 summer season. The right hand curve represents the solubilities of sodium and calcium in a chloride solution at the freezing point. All the dots are clearly situated on the left hand

Table 1. Sequential changes in chemical composition and specific gravity of the saline water in Don Juan Pond and occurrence of antarcticite.

Sample No.	1	2	3	4	5
Sampling date	11 Oct. 1961 (1961–62)	16 Dec. 1962 (1962–63)	30 Dec. 1963 (1963–64)	06 Jan. 1965 (1964–65)	03 Dec. 1965 (1965–66)
Water Teperature (°C)	—	—	6.45	10.4	3.5
Specific gravity at 24°C	1.251	1.351	1.380	1.386	1.375
Na (g/kg)	11.5	4.11	2.16	1.63	2.66
K 〃	0.16	0.15	0.23	0.26	0.23
Ca 〃	114.0	123.9	132.2	137.1	131.7
Mg 〃	1.20	1.8	2.6	1.8	2.3
Cl 〃	212.0	229.4	247.1	251.1	243.6
SO_4 〃	0.011	0.0	0.0	0.0	0.0
HBO_2 〃	—	0.01	0.004	0.004	—
Br 〃	—	0.112	0.120	0.123	—
Sr 〃	—	—	—	—	—
Evaporation residue at 180°C (g/kg)	—	361.9	388.8	390.6	384.5
Occurrence of antarcticite	Presumably no	No	Observed	Observed	Observed
Sampling by	G.H. Meyer et al. (USA)	H. Fukushima	T. Torii N. Yamagata T. Cho Y. Yoshida	T. Torii T. Cho Y. Yoshida Z. Hirayama J. Sugiyama	T. Torii N. Yamagata M. Shima A. Koga

6	7	8	9	10
28 Dec. 1968 (1968–69)	11 Nov. 1969 (1969–70)	07 Jan. 1971 (1970–71)	15 Jan. 1971 (1971–72)	10 Dec. 1971 (1971–72)
10.0	—	10.6		7.0
1.361	1.298	1.283	1.216	1.288
3.51	9.89	11.9	11.6	10.4
0.20	0.12	0.13	0.13	0.12
127.1	107.2	98.2	73.8	104.0
1.8	1.6	0.7	1.2	1.3
235.5	209.1	197.0	151.2	201.0
0.0	0.00	0.0	0.02	0.0
0.005	0.003	—	—	—
0.111	—	—	—	—
—	—	—	0.83	0.93
370.7	328.6	334.3	247.3	355.1
No	No	No	No	No
T. Torii N. Yamagata	A.M. Bromley (NZ)	T. Torii Y. Yoshida Y. Yusa K. Morikawa	T. Torii Y. Yoshida Y. Yusa K. Morikawa	T. Torii Y. Yusa K. Nakao T. Hashimoto

11	12	13	14 (SW site)	15 (East site)
30 Dec. 1972 (1972–73)	17 Nov. 1973 (1973–74)	25 Apr. 1974 (1973–74)	09 Jul. 1974 (1973–74)	09 Jul. 1974 (1973–74)
9.1	2.8			
1.339	1.324	1.224	1.208	1.134
3.68	6.73	6.19	8.13	6.81
0.14	0.14	0.10	0.08	0.05
127.0	112.7	81.1	74.1	48.23
1.5	1.6	1.1	1.1	0.70
234.6	215.7	157.9	147.6	98.71
0.0	0.00	0.00	0.03	0.28
—	0.003	0.003	0.002	—
—	—	—	—	—
—	—	—	—	—
368.2	339.4	265.6	242.6	174.3
No	No	No	No	No
T. TORII Y. YOSHIDA S. NAKAYA T. HASHIMOTO	T. TORII F. MORELLI	A. M. BROMLEY (NZ)	A. M. BROMLEY (NZ)	A. M. BROMLEY (NZ)

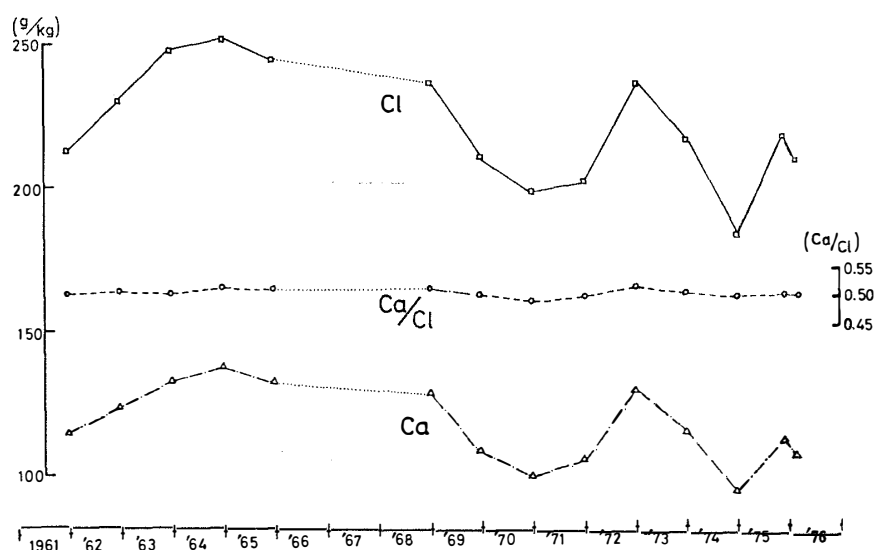| 16	17	18	19	20
07 Dec. 1974 (1974–75)	14 Dec. 1974 (1974–75)	09 Jan. 1975 (1974–75)	18 Dec. 1975 (1975–76)	05 Jan. 1976 (1975–76)
6.9	8.2	6.3	2.5	
1.233	1.255	1.265	1.324	1.318
8.97	9.83	9.85	6.76	6.73
0.09	0.11	0.12	0.11	0.13
81.85	88.40	91.48	110.0	105.0
1.1	1.2	1.2	1.7	1.6
162.8	175.5	182.0	216.3	207.5
0.03	0.01	0.03	0.0	0.0
0.002	0.003	0.003	—	—
—	—	—	0.103	0.098
—	—	—		
273.8	274.1	293.1		
No	No	No	No	No
T. TORII	T. TORII O. WAGURI	T. TORII	K. KAMINUMA	K. KAMINUMA

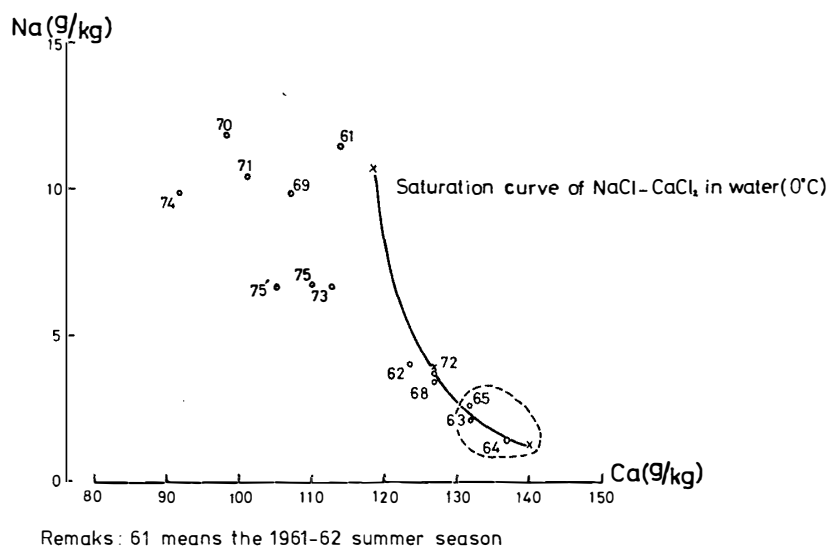Fig. 1. *Sequential changes in the main chemical components of the pond water during 1961–1976.*

Fig. 2. *Observed relationship between Na and Ca concentrations in the pond water during 1961–1976.*

side of this curve except in five seasons 63, 64, 65, 68 and 72, where the dots are located on or quite close to the curve. And in cases where the calcium concentration exceeded 130 g/kg, antarcticite was observed in the pond (Torii *et al.*, 1970). On the other hand, when the concentration of calcium was low, the concentration of sodium was comparatively high. In other words, there seems to be an inverse correlation between the calcium and sodium concentrations.

Furthermore, in ordinary years, practically no sulphate was detected except

when the water was sufficiently dilute. For example, in 1961 and 1974 as shown in Table 1, a detectable amount of sulphate was present. This amount was probably supplied through the interface of water and sediment and/or through ground water. Therefore, a balance study in the liquid and the salt phases of the pond should also be correlated by a study of the sediment and ground water layers around the pond.

In DVDP 13 drilling, the ground water was taken at the depths of 5.4 m and 8.8 m. The chemical compositions of the pond water and the ground water are compared in Table 2. The relative concentration of each element is similar

Table 2. Chemical composition of ground water in the Don Juan basin.

Sample		Ground water No. 1	Ground water No. 2	Pond water
Depth from the ground		548 cm	880 cm	10 cm
Specific gravity		1.119	1.121	1.265
Na	(g/kg)	5.04	5.10	9.85
K	//	0.071	0.072	0.12
Ca	//	44.39	46.66	91.48
Mg	//	0.58	0.60	1.2
Cl	//	87.41	92.58	182.0
SO_4	//	0.367	0.353	0.03
Br	//	0.034	0.037	0.075
HBO_2	//	0.007	0.004	0.003
Na/Cl	(equiv. %)	8.88	8.49	8.33
K/Cl	//	0.074	0.071	0.059
Ca/Cl	//	89.58	89.14	88.92
Mg/Cl	//	1.96	1.89	1.92
SO_4/Cl	//	0.31	0.28	0.012
Br/Cl	//	0.017	0.018	0.018
HBO_2/Cl	//	0.006	0.003	0.001

in all aspects with the only exception of SO_4 abundance. In other words, the SO_4/Cl ratio differs considerably. But in both waters the sulphate concentration approximately corresponds to a saturated solution of $CaSO_4$ in a calcium chloride solution. The comparison of the relative concentrations of K/Na and Mg/Ca in pond water and ground water with sediment leachate should lead to the conclusion that the sediment layer, containing much K, Mg and SO_4 as compared with contemporary saline water, was formed before the formation of the present Don Juan Pond.

Table 3. Mineralogical and chemical characteristics of the surface deposits.

Location	Characteristics	Identified minerals by X-ray diffractometer	Soluble %/dry	Equivalent % in soluble portion					
				Na	K	Ca	Mg	Cl	SO₄
Pond	Hexagonal platy-, prysmatic-crystal, needle	Antarcticite (CaCl·6H₂O)	100	1.60	0.03	94.8	3.63	100.0	—
	Crystal, toitoise shaped on top of antarcticite above water level	Halite							
	White evaporites on the surface of rock	Halite, antarcticite, gypsum	93.3	75.6	0.02	22.9	1.47	100.0	—
	Deposits on shoreline	Halite, antarcticite, gypsum	68.9	86.0	0.03	13.5	0.43	99.3	0.7
Flat basin	Brownish mud on pond bottom	Halite, antarcticite, gypsum	24.3	48.6	0.06	49.8	1.45	97.0	3.1
	Brownish deposits on the rough surface near pond	Halite, antarcticite, gypsum	36.6	78.2	0.04	21.3	0.49	97.5	2.5
	Sandy deposits, 10 m west from pond	Halite	66.6	92.3	0.02	7.6	0.09	99.7	0.3
	Sandy deposits, 60 m west from pond	Halite	72.5	86.5	0.01	13.4	0.10	98.9	1.1
	Yellowish brown deposits, 200 m east from pond	Halite, gypsum	37.9	79.8	0.04	19.8	0.40	92.7	7.3
Slope	Deposits, 1m high from the basin	Halite, antarcticite	4.0	8.92	0.43	88.8	0.18	100.0	0.0
	Deposits, 2.1 m "	Halite, gypsum	18.5	96.6	0.06	3.3	0.05	99.5	0.5
	Deposits, 7.75 m "	Halite, gypsum	66.3	97.5	0.03	2.3	0.03	98.8	1.2
	Deposits, 9.85 m "	Halite	67.0	98.1	0.02	1.9	0.04	99.2	0.8
	Deposits, 12 m "	Halite, chlorite, gypsum	44.6	91.5	0.18	8.2	0.16	94.0	6.0
	Bluish sand, 153 m "	Halite, chlorite, mica vermiculite	8.1	13.0	0.42	55.5	31.0	100.0	—

〔南極資料〕

3. A Study of Evaporites in and around the Pond

In Table 3 are shown the results of powder X-ray diffractometry and chemical analysis of water-soluble portion of the deposits present in the Don Juan basin, and the identified minerals and their characteristics are shown in a rough sketch in Fig. 3. All the white crystals formed in the liquid phase of the pond were
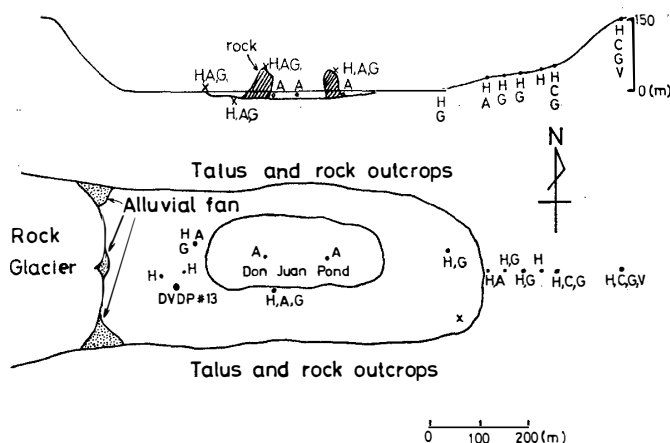

Fig. 3. Distribution of identified minerals in and around Don Juan Pond.
A: antarcticite, H: halite, G: gypsum, C: chloride, V: vermiculite.

antarcticite, while the majority of the white crystals on the adjacent flat basin of the pond was halite with only a small percentage of antarcticite and gypsum. The east side slope was also dominated by halite, with chlorite and vermiculite at higher elevations. The water-soluble fraction around the pond locally varied from 4.0 to 72.5% on the dry basis.

In Table 4 are shown the data for a profile sample obtained in 1964–65 by hand-digging at 300 m ESE of the pond. The results are schematically reproduced

Table 4. Profile distribution of soluble chemical components
(at 300 m ESE from the pond).

| Depth from the surface (cm)	Characteristics	Soluble %/dry	Equivalent % in soluble portion					
			Na	K	Ca	Mg	Cl	SO₄
0– 11	Halite, sand, clay	4.24	8.41	0.08	89.7	1.75	81.3	18.7
11– 23	Silty sand	4.25	13.0	0.07	84.5	2.36	81.6	18.4
23– 36	White crystal, sand, clay	5.58	10.7	0.12	87.6	1.53	82.3	17.7
36– 47	Salt, clay	5.78	17.7	0.11	80.6	1.54	85.4	14.6
47– 65	Silty sand, white crystal	17.9	68.0	0.07	31.3	0.67	91.8	8.20
65– 80	Sand, medium to coarse	8.49	11.0	0.10	86.7	2.18	93.5	6.50
80–113	Sand, coarse	47.2	82.7	0.04	16.9	0.41	95.6	4.37
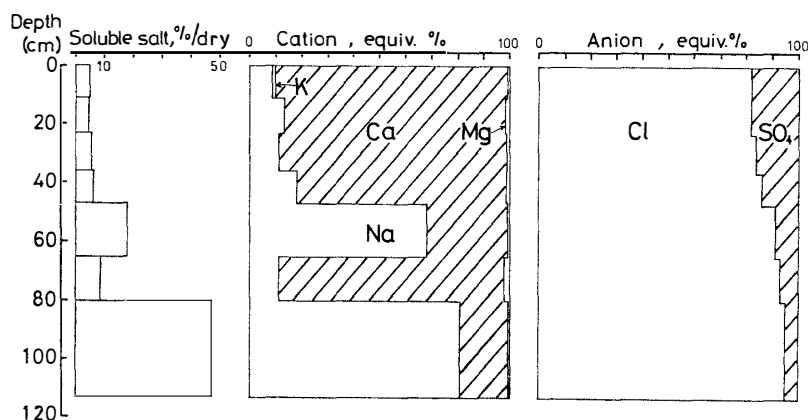
Fig. 4. Profile distribution of soluble chemical components in the surface layer of the basin (at 300 m ESE from the pond).

from Table 4 and shown in Fig. 4. Soluble salts amounted to almost 50% of the dry sediments in which white crystals of halite dominated in the deeper layer—80–113 cm. In contrast, soluble salts were only 4–8% in the uppermost layer. This suggests the leaching of soluble salts by inflow and pond water from the surface layer.

The size of the flat basin of the pond is about 400 m×900 m. By assuming 10% of the deposits is soluble, and the volume weight of the deposits is 2, the total salt in the basin to the depth of 1 m should amount to 72,000 t.

4. Core Analysis of DVDP 13 Drill

DVDP 13 drill core was obtained at about 50 m SW from the pond between 8 January and 13 January 1975, using the pond water for circulation. Coordinates of the borehole are 77°33′ 19.7″ S, 161°09′ 53.4″ E and 118.43 m above sea level. Continuous core recovery there provides a record of 12.67 m of sorted sands and silt, 39.53 m of the lowermost units of a Ferrar sill, and 22.78 m of migmatite. Water-saturated sands contain no recognized secondary minerals. 27 samples of the core were studied in order to get information about the soluble salt distribution in the deeper layers of the basin.

Table 5 shows the results of the powder X-ray diffractometric identification of the core samples. In the upper two layers, gypsum dominated and no halite was found. This probably means only that the soluble halite was leached by the circulating water during drilling. Another remarkable find was the presence of a comparatively large amount of calcite in the basement fractures, especially in dolerite. The presence of this calcite in the basement can be used in the continuing attempt to prove the sea water origin for Don Juan's salt, since calcite is the first evaporite in sea water which is concentrated in frigid conditions.

Table 5.   X-ray identifications of DVDP 13 core.

Depth (cm)	Identified minerals	Depth (cm)	Identified minerals
36.3	Gypsum	1249	Calcite, fluorite
196	Gypsum	1360.7	Mica
306	Mica	1380.7	Calcite, fluorite
821.9	Mica	3811.5	Calcite
880.3	Mica	4388.1	Calcite
1115	Mica, zeolite	4677.6	Calcite, fluorite
1120	Chlorite	4936.7	Calcite
1139	Mica	5183.1	Calcite

Remarks: Quartz and feldspar were identified in all layers to the basement, but description
        was omitted.

After studying the secondary minerals, 19 core samples in the sediment
layers were extracted with water (water-soluble part) first, and the residue was
treated by perchloric acid (water-insoluble part). The results of the chemical
analysis of both soluble and insoluble parts are summarized in Tables 6 and 7.
The perchloric acid effectively extracted magnesium and sulphate, and probably

Table 6.   Water-soluble salt in DVDP 13 core.

Depth (cm)	Soluble %/dry	Equivalent %						
		Na	K	Ca	Mg	Cl	SO₄	NO₃
36.3	4.33	5.63	0.14	93.2	1.05	68.6	31.3	0.08
156	1.90	8.48	0.39	89.9	1.26	99.6	0.38	0.06
196	4.46	5.98	0.13	93.9	nil	68.7	31.3	nil
306	1.76	8.54	0.54	90.1	0.78	99.8	0.25	nil
604	3.01	7.82	0.21	91.1	0.91	99.7	0.24	0.07
720	1.89	9.30	0.80	89.2	0.73	99.9	0.08	nil
703.5	1.93	8.67	0.65	88.6	2.09	99.9	0.08	nil
735.6	1.64	9.01	0.72	86.4	3.88	99.5	0.38	0.07
817	1.47	8.44	0.71	90.2	0.69	100.0	nil	nil
821.9	2.27	7.94	0.32	88.2	3.55	94.4	5.53	0.05
854.9	1.41	8.05	0.51	90.8	0.61	99.9	0.13	nil
880.3	2.03	8.39	0.48	88.0	3.09	99.5	0.47	0.06
890	2.41	8.34	0.68	90.2	0.73	99.9	0.10	nil
1005	2.54	8.13	0.16	91.7	nil	99.8	0.19	0.09
1102	2.58	9.88	1.72	86.5	1.88	99.9	0.06	nil
1115	2.58	11.3	1.50	84.4	2.85	98.8	1.08	0.16
1120	2.07	9.33	0.95	86.2	3.50	99.6	0.38	nil
1139	2.29	8.96	0.55	90.5	nil	99.9	0.05	nil
1200	1.59	9.06	0.53	88.5	1.93	99.8	0.09	0.07

Table 7.   HClO₄-soluble salt in DVDP 13 core.

Depth (cm)	Equivalent %					
	Na	K	Ca	Mg	Cl	SO₄
36.3	1.68	0.01	86.7	11.0	1.47	98.5
156	5.94	1.96	47.1	45.0	67.0	33.0
196	1.81	0.58	85.7	11.0	1.58	98.4
306	7.48	2.03	51.3	39.2	79.8	20.2
604	5.50	1.51	58.0	35.0	51.8	48.2
720	6.45	1.51	64.3	27.8	70.0	30.0
730.5	6.12	1.15	68.5	24.3	91.8	8.20
735.6	6.48	2.50	62.7	28.3	96.9	3.05
817	6.04	1.86	64.7	27.4	69.8	30.2
821.9	5.95	1.53	66.3	26.2	68.3	31.7
854.9	5.98	1.95	67.4	24.6	88.0	12.0
880.3	5.88	2.17	62.9	29.0	87.9	12.1
890	4.86	1.73	64.6	28.8	62.0	38.0
1005	5.18	1.55	66.7	26.6	57.5	42.5
1102	7.72	1.91	65.6	24.8	90.7	9.3
1115	12.4	2.99	36.5	48.0	83.5	16.5
1120	11.4	2.33	55.8	30.5	98.4	1.62
1139	8.67	2.00	57.1	32.3	87.6	12.4
1200	4.54	1.28	69.2	24.9	68.6	31.4

carbonate, from the core. The results can be summarized that (1) the major component of the soluble part is calcium chloride (more than 90%), (2) both parts of the core from 36.3 cm and 196 cm depth contain a large quantity of sulphate and (3) the water-insoluble part is enriched by K, Mg as compared with soluble part. Moreover, water-soluble chloride concentrations in the upper layers were almost one-third of those concentrations in the hand-drilled core, but the sulphate concentrations there showed little difference. It can be suggested then, that the water-soluble salts in DVDP core were artificially depleted because of the circulating water.

Fig. 5 shows the vertical distribution of the major components in both parts. The principal component is calcium chloride, and the total amount of the salts in each layer does not change markedly with depth. The average is about 1 meq per gram of dry sediment. This suggests a continuous sedimentation up to a depth of 13 m during the concentration—deposition processes of paleolake water in the Don Juan basin.
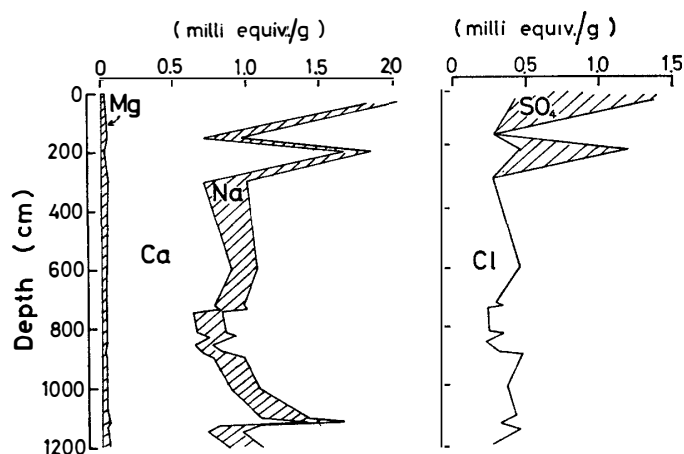
Fig. 5. Profile distribution of H_2O- and $HClO_4$-soluble salt in DVDP 13 core.

5. Discussion

5.1. Salt balance in the Don Juan basin

Using the above data the following inventory can be given of the salt found in the Don Juan basin. As mentioned before, the basin can be divided roughly into three components, namely, the liquid phase and solid phase of the pond, and the flat basin and the slopes around it.

The salt balance within the system involving the liquid and solid phases of the pond can be analyzed on the basis of data shown in Table 1. In 1964–65, the salinity was the highest (sp. gr.: 1.386) and the size of the pond was the smallest (105 m×205 m, 10 cm deep), while in 1974–75 the specific gravity was 1.265, and the size much larger (134 m×326 m, 15 cm deep). The total NaCl in the liquid phase was 12.4 t in 1964–65 and 192 t in 1974–75; the difference (179.6 t) should have been present in the solid phase in 1964–65. The total $CaCl_2 \cdot 6H_2O$ in the liquid phase was 2,240 t in 1964–65 and 3,840 t in 1974–75; the difference (1,600 t) should have been present in the solid phase (as antarcticite) in 1964–65.

The volume of each part of the pond can be calculated as follows. For example, the smallest volume of the pond, 2,150 m³, was observed in the 1964–65 summer when the salinity was the highest. The volume was the largest, 6,550 m³, in the 1974–75 summer when the salinity was the lowest. In both cases, the total amount of sodium chloride and even that of calcium chloride in the liquid and solid phases of pond itself is of the order of 100 and 1,000 tons, respectively, which are by far smaller than their amounts in the flat basin and slopes around the pond.

The volume of the basin itself can be calculated on the basis of its surface

area and the thickness of the deposits. By assuming the former as 400 m × 900 m and the latter as 13 m and the salt content as 72,000 t per 1 m thickness as stated before, the total salt in the basin can be calculated as 940,000 t. This means more than 95% of salt in this basin is present in the deposit phase around the pond.

Then, the most critical question comes out. What is the origin of such a large amount of salt? There have been continued debates on this matter particularly related to sea water origin and rock weathering in combination with salt spray from the sea. The following are the calculations based on the sea water origin hypothesis.

Cartwright (1974) and others report at least two, possibly three, higher lake levels where the lake water stood well above the present almost flat basin floor. Using 20 m as a highest paleolake shoreline, the depth of sea water then could have been at least 20 m plus the thickness of the deposits on the basement, totalling 33 m. Thus the volume of original sea water can be calculated as 1.2×10^7 m^3 as shown in Table 8. Of course, the possibility of higher paleolake shoreline can not be excluded. Geomorphological observations in the Wright Valley, particularly the east side slope of Don Juan Pond can give a maximum estimate of 150 m and in this case the volume of sea water can be calculated as 5.9×10^7 m^3.

Table 8. Estimates of the volume of original sea water.

1) Estimated volume from total salt deposit	2.6×10^7 m^3
A) Calculation from K, Mg, SO$_4$ and Cl	1.2–2.2×10^7 m^3
B) Calculation from Ca	36.6×10^7 m^3
2) Estimated volume from ancient shoreline	1.2×10^7 m^3 (5.9×10^7 m^3)

Another way of estimating the volume is on the basis of the total salt amount of 940,000 t present in the basin. By assuming the amount of total salt deposits comes from simply the evaporation residue of sea water, the volume can be estimated as 2.6×10^7 m^3, and this value is roughly equal to the estimate based on a paleolake shoreline, as mentioned before.

Such estimation can be made also on the basis of each major chemical element such as potassium, magnesium, sulphate and chloride present in the basin. As shown in Table 8, when the estimates are made on the basis of these elements, the values ranged from 1.2 to 2.2×10^7 m^3, which are in the same order of the above estimation. It should be mentioned here that the estimate from the chloride content resulted in 0.5×10^7 m^3, if a correction factor of three was not applied to the analytical results obtained from drill cores.

A very large estimate based on the calcium content, reaching 37×10^7 m^3 indicates a depletion in sodium and chloride, an enhancement in calcium in the

salt deposits in comparison with sea water. This contradiction could be explained by assuming other sources of salt such as rock weathering, sea water spray, etc. The authors have not yet encountered any evaporite layers dominated with potassium, magnesium and sulphate before the DVDP, but the recent data obtained from the DVDP core analysis indicate that such elements are more abundantly present in the basin than we expected from the surface deposits and pond water. This is one of the outcomes of the DVDP.

5.2. Water balance in the Don Juan basin

Several interesting problems arise from this preliminary discussion. On the water balance in the Don Juan basin a little comment will be given using the above data. A question is that how many years did it take for the formation of the present pond from the paleolake?

The basic equation of water balance we used is shown in Fig. 6. In this equation, W_s is the volume of the original water body and is assumed as the estimated value based on the total salt amount just mentioned, namely 2.6×10^7 m^3. E_o is evaporation rate and the value 400–500 mm per year were taken from the observed values in Lake Vanda by YUSA (1972).

Assuming a stationary state between evaporation and inflow in the Don Juan Pond, the inflow rate R can be calculated as 1.5×10^4 m^3, from the equation $E_oA_1 = R$. This value is in good coincidence with the observed value of 1×10^4 m^3. The authors observed an inflow rate at the alluvial fan west of the pond as 0.0087 m^3/s on a warm day in late December.

In Fig. 6, A_1 is the area of the present pond and A_o is the area of the original pond. And t_1 is the time required for the formation of the present pond.
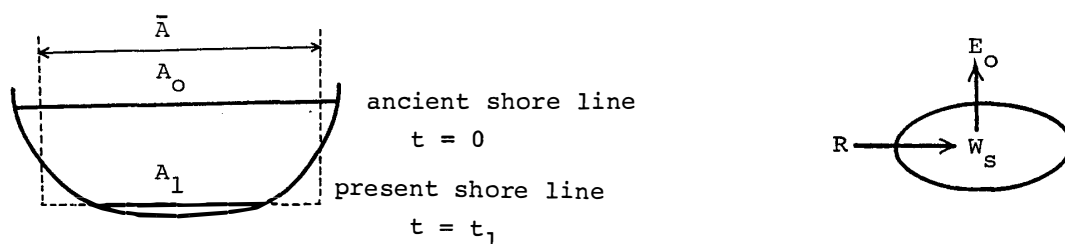

Fig. 6.   Age estimation of the pond based on water balance.

Water balance equation : $Rt_1 + W_s = E_0 \int_0^{t_1} A dt$
$$= E_0 \bar{A} t_1$$

W_s: *Volume of original sea water* 2.6×10^7 m^3
E_0:   *Evaporation rate*   *400–500 mm/y*
$E_0A_1 = R$ $\bar{A} = (A_0 + A_1)/2$
$$= 2 \times 10^5 \; m^3$$
R: *Inflow rate* 1.5×10^4 m^3/y
t_1:   *Time required for the formation of the present pond*   *300–400 y*

Thus, t_1 can be estimated as about 300–400 years. Of course, we do not think this estimate is quite accurate, because of the assumption of constant rates of evaporation and inflow, but think one hundred years order of magnitude is a hint for the time required for the formation of the present pond.

6. Conclusion

The saline waters in the Dry Valleys have a complex origin. With regard to the question of the salt origin, several workers are still studying microelements and stable isotopes such as δD, $\delta^{18}O$ and $\delta^{32}S$ to help clarifying this, but in evaluating the possibility of earlier marine invasion in the Wright Valley, the geochemical studies on the liquid and solid phases in the basin appear to have been brought about by a combination of the introduction of sea water and the concentration of these and other glacial melt water flowing into the lake by a sublimation-freezing mechanism.

This paper deals with just one aspect of our work related to the formation of the Don Juan basin and the questions concerning the origin of its salt. A much more detailed report will be given later.

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