ORIGIN OF SALT IN ANTARCTIC SALINE LAKE WATERS THROUGH TRACE ELEMENT ANALYSIS

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Abstract: The origin of trace elements in Antarctic saline lake waters is still not clear. Waters of five Antarctic saline lake and ponds in the Wright Valley and the Taylor Valley, and one coastal glacier ice were analyzed by the neutron activation method. Three possible origins, connate sea water, rock weathering and tropospheric aerosol particle, were investigated. The correlations of chemical constituents between the South Pole aerosol particle and the lake and pond waters indicate that trace elements in the Antarctic saline lake and pond waters might have been derived mostly from aerosol particles.

1. Introduction

There have been few geochemical studies on trace elements in Antarctic saline lakes. WEAND *et al.* (1976) reported the vertical distribution of six trace metals in the water of Lake Bonney in the Dry Valleys area. They also discussed the toxicity of trace elements to biota. SANO *et al.* (1977) reported the vertical distribution of iron, manganese, copper, zinc, cadmium and lead in the water of Lake Nurume, Syowa Oasis. BOSWELL *et al.* (1967a, b) measured six trace metal concentrations of the bottom waters in five lakes in the Dry Valleys area. They concluded that zinc and manganese in the Lake Vanda water were not derived directly from sea water. MASUDA *et al.* (1982a) suggested that the pathway of trace elements at Lake Vanda is tropospheric aerosol–precipitation–glacier–glacial melt water–Lake Vanda.

This study presents the trace element data of waters of Lake Fryxell, Canopus Pond, Labyrinth L-4 Pond and Lower Wright Glacier together with those of Lake Vanda and the Onyx River. The purpose of this study is to elucidate the origin of trace elements in the Antarctic saline lake waters.

2. Collection of Samples

Water samples of Lake Vanda were taken with a 1 liter Kitahara type water sampler made of stainless steel at site R (water depth 64.4 m) on January 7 and 8, 1979. Two liters of water samples were taken at depths of 4, 10, 20, 30, 40, 45, 50, 55, 60 and 64 m. The water samples from the Canopus Pond, near Lake Vanda, were taken with a polyethylene jug on January 9, 1979. Water samples of the Don Juan Pond and an unnamed pond in the Labyrinth area (laboratory name; L-4) were taken on January 16, 1979, and the Lake Fryxell surface water and the Onyx River water were collected on January 17, 1979 in the same manner as at the Canopus Pond. Water samples were immediately poured into 1 liter polyethylene bottles and 3 m*l* of 6 M hydrochloric acid (super special grade) was added to adjust the pH to 1.5–1.8. The bottles were kept in polyethylene bags to prevent contamination during transportation and storage. The bottles were previously soaked in 6 M nitric acid for one week. All the water samples were not filtered.

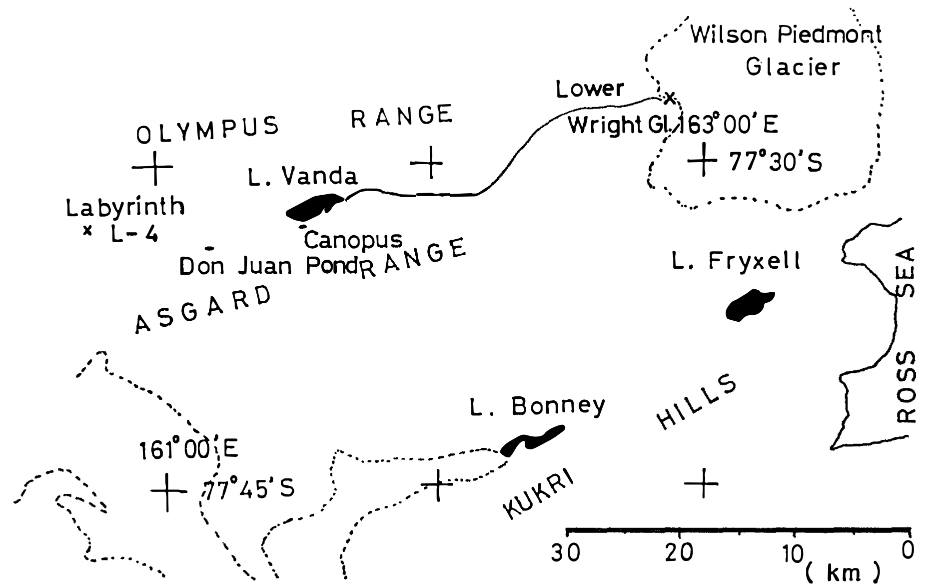


Fig. 1. Sampling locations in the Wright Valley and the Taylor Valley, Victoria Land, Antarctica.

Ice sample of the Lower Wright Glacier was collected at the terminus cliff of the glacier near the Lower Wright Hutt in the Wright Valley. The height of the cliff was about 20 m and the sampling height was 1.5 m above the bottom. The sampling sites are shown in Fig. 1.

3. Determination of Trace Elements

For the water samples from the Onyx River, Lake Vanda (4–45 m), Canopus Pond, Lake Fryxell, Labyrinth L-4 Pond and Lower Wright Glacier, 100 m*l* of each sample was dried under an infrared lamp. The residue was dissolved with nitric acid and then dried again in the same manner. The residue was dissolved again with 2.5 m*l* of nitric acid, the acid solution was transferred into a quartz tube, and then evaporated in an electric oven. The residue in the quartz tube was subjected to irradiation.

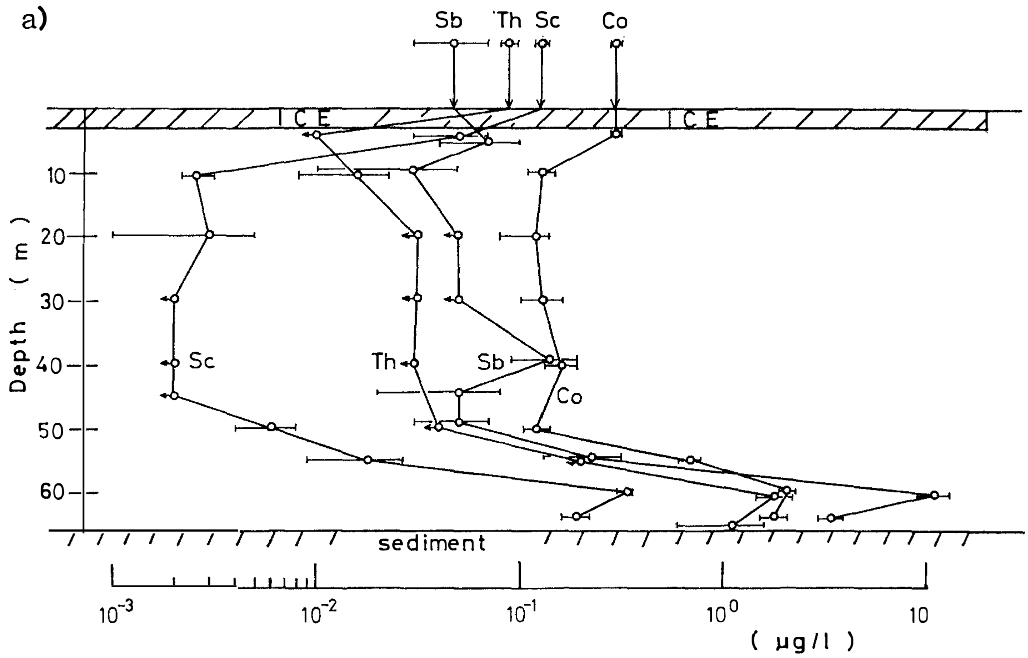
The water samples of Lake Vanda (50–64 m) and the Don Juan Pond were subsampled in beakers, nitric acid was added to each sample, and then the solution was evaporated. The residue of 0.6 to 3.2 g was weighed and sealed in polyethylene bag. The standards containing various amounts of Cr, Fe, Co, Ni, Zn, Sr and Cs were prepared in the same manner. AGV-1 (USGS), Orchard Leaves (NBS SRM-1571) and Fly Ash (NBS SRM-1633a) were used as standard reference materials.

Analytical procedures for samples and standards are as follows. The samples and the standards were irradiated with the F-ring or RSR of TRIGA-II reactor (Rikkyo University) for 18 hours, irradiated samples and standards were cooled for about one month, and cooled samples and standards were counted for 3 to 18 hours with the Ge(Li) detector. The procedures for other elements were reported previously (MASUDA *et al.*, 1982a for Mn; MASUDA *et al.*, 1982b for Cu, Fe, Ni and Al).

4. Results and Discussion

The vertical distribution of trace elements in the Lake Vanda and Onyx River waters is shown in Figs. 2a and 2b. Arrows in the top of the figure indicate the concentrations of trace elements of inflowing water (Onyx River). Ranges denote the standard deviation of errors derived from counting statistics.

All the vertical profiles of the concentrations of elements show a trend of abrupt increase in layers deeper than 40 m. The behaviors and the chemical forms of Cu, Al and Fe in the Lake Vanda water were discussed previously (MASUDA *et al.*, 1982b). The vertical profile of copper shows a good correlation with that of chlorinity which



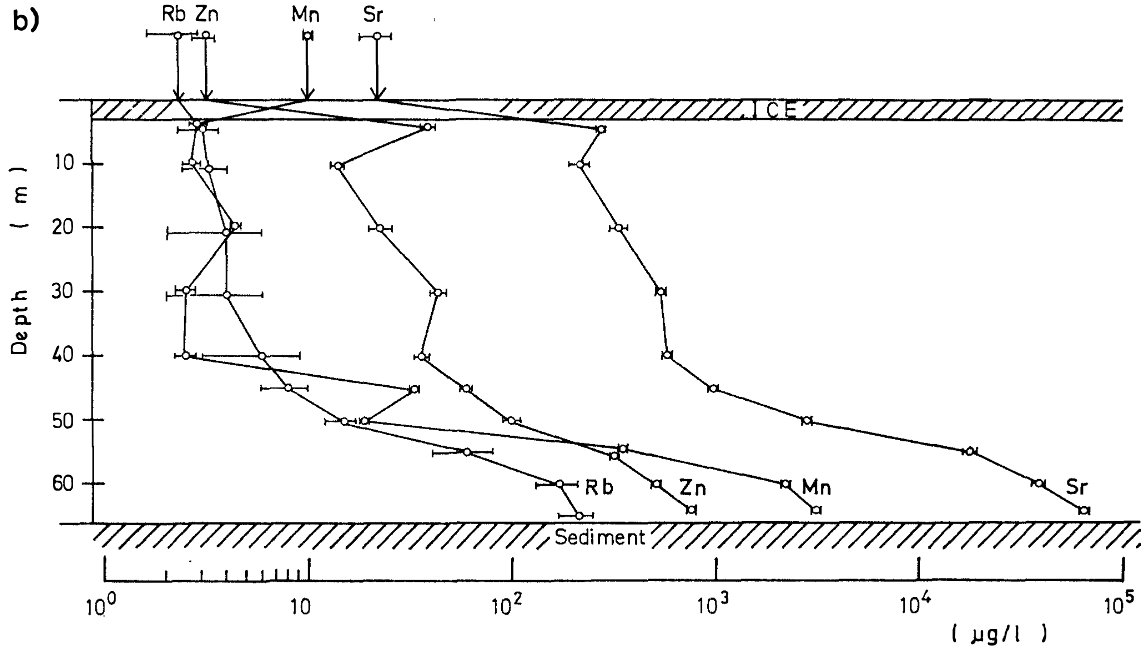


Fig. 2. Vertical distribution of trace elements in Lake Vanda, (a) Sc, Th, Sb, Co and (b) Rb, Zn, Mn, Sr. Arrows on the top of the figure indicate contents of elements in the Onyx River water.

Table 1. Concentrations of trace elements in saline lake and pond waters and glacier ice in the Dry Valleys area, Antarctica.

Element	Lake Fryxell (µg/l)	Canopus Pond (µg/l)	Don Juan Pond, main pond (µg/l)	Labyrinth L-4 Pond (µg/l)	Lower Wright Glacier (µg/l)
Sc	0.018±0.002	0.026±0.002	0.11±0.05	0.025±0.006	0.27±0.01
Cr	2.3±0.2	<0.7	<40	<2	6.4±0.4
Mn	3.93±0.41	4.43±0.30	800±40	0.80±0.04	18.3±0.8
Fe	90±20	50±20	800±500	<50	1240±70
Co	0.24±0.03	0.10±0.02	1.2±0.5	0.16±0.07	0.66±0.06
Zn	7.5±0.9	4.8±0.7	270±30	3±2	71±4
Rb	<0.5	<4	700±500	<20	<0.8
Sr	<6	0.019±0.002	1600±100	0.0017±0.0002	—
Sb	<0.03	0.04±0.04	4±2	0.5±0.2	0.045±0.030
Cs	0.02±0.02	0.35±0.02	46±2	0.64±0.07	<0.013
Ce	0.09±0.04	0.7±0.3	<30	2.4±0.9	2.1±0.1
Eu	0.010±0.008	0.017±0.007	<0.3	0.05±0.04	0.040±0.009
Hf	<0.008	<0.03	<2	0.10±0.08	0.073±0.020
Th	0.011±0.006	<0.06	<3	<0.2	0.20±0.02

All data of lake and pond waters are obtained for surface layers.

is not removed significantly from the water column. This good correlation indicates that copper behaves together with chloride ions. The concentration of aluminum is nearly constant at all depths. Aluminum would not be dissolved even under the reducing condition of Lake Vanda's deep water, and could not be diffused upward. The concentration of iron is almost constant from the surface to a 55 m layer but below this layer iron concentration increases abruptly. In the layer above 55 m, iron should be present as a trivalent solid form and precipitated to the bottom where iron is reduced to a divalent soluble form and diffused upward. This process might have been repeated to result in the observed profile of iron. The results from the Canopus Pond, the Don Juan Pond, Labyrinth L-4 Pond, Lake Fryxell and the Lower Wright Glacier are presented in Table 1.

Many reports presented the distribution and discussed the origin of major elements in the Antarctic saline lake waters (JONES and FAURE, 1967; MORIKAWA *et al.*, 1975; NAKAYA, 1977; TORII *et al.*, 1979; TORII and YAMAGATA, 1981; HARRIS and CARTWRIGHT, 1981). However, there exist few geochemical studies on trace elements in the Antarctic saline lake waters. BOSWELL *et al.* (1967a, b) reported the concentrations of six metals in the bottom water of Lake Vanda and suggested that the origin of these elements was not sea water. The origin of trace elements is still not clear.

Three possible origins of trace elements are considered. 1) Connate sea water origin: Some reports proposed a sea water origin for major elements (ANGINO and ARMITAGE, 1963; CRAIG, 1966; NICHOLS, 1966). This origin can be extended to air-borne sea salt which has the same composition as that of sea water. 2) Rock weathering origin: JONES and FAURE (1967) suggested that major elements could be derived from basement rock and soil weathering. 3) Air-borne particle origin: Because air-borne particle is considerably enriched in heavy metals compared with sodium and aluminum (DUCE *et al.*, 1975), such particle could supply heavy metals to polar ice either through dry fallout or precipitation. MASUDA *et al.* (1982a) suggested that the pathway of trace elements in Lake Vanda was tropospheric aerosol particle–precipitation–glacier–glacial melt water–Lake Vanda.

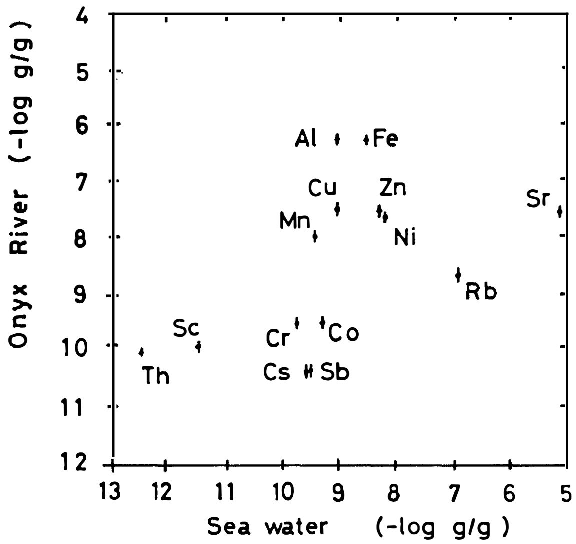


Fig. 3. Relationship of trace element contents between the Onyx River water and the sea water (modified from MASUDA *et al., 1982a).*

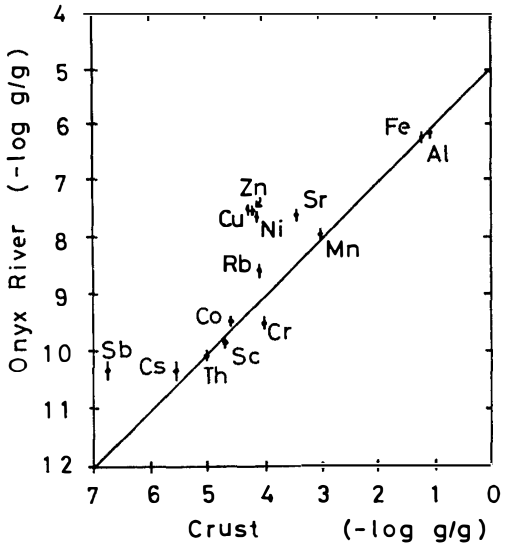


Fig. 4. Relationship of trace element contents between the Onyx River water and the continental crust (modified from MASUDA *et al., 1982a).*

The Dry Valley Drilling Project (DVDP) studies provided evidence that during the Miocene period there was a fjord in the Wright Valley (BRADY, 1979). Results obtained for trace elements in the Lake Vanda water do not support the connate sea water origin, because the chemical composition of the inflowing water (Onyx River) is not identical with that of sea water (Fig. 3). Considerable rock weathering materials have been brought to the lake through the Onyx River. The relationship between the trace element contents of inflowing water and the continental crust is shown in Fig. 4. Assuming that aluminum came from crustal material, crustal material is considered to be a major source for Fe, Mn, Co, Sc, Th and Cs, and a minor source for Sr, Rb, Cu and Zn.

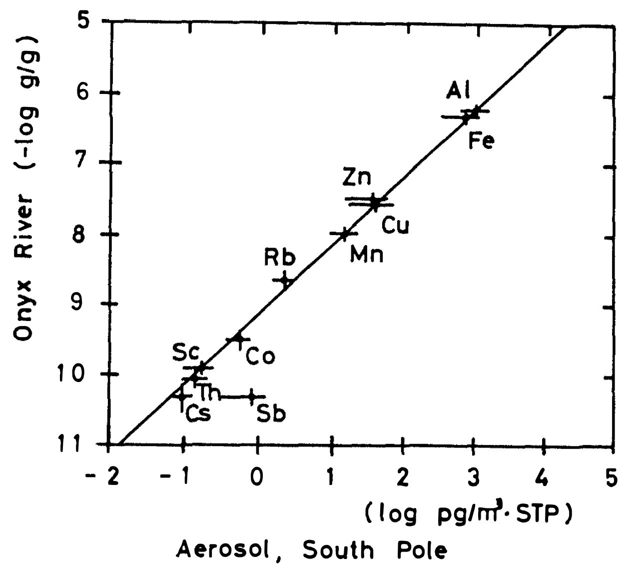


Fig. 5. Relationship of trace element contetns between the Onyx River water and the South Pole aerosol particle (data of aerosols are from MAENHAUT et al., 1979).

The relationship of trace element contents between the Onyx River water and tropospheric aerosol particle at the South Pole (MAENHAUT *et al.*, 1979) is shown in Fig. 5. The chemical compositions of inflowing water and aerosol particle show a good agreement except for Sb, and they also have a similar composition to Antarctic snow (BOUTRON and LORIUS, 1979; BOUTRON and MARTIN, 1980). Elements, such as Cu, Ni and Zn in the Onyx River water that are anomalously enriched compared with those in sea water and crust, are also enriched in aerosol particle in the Antarctic region (NAKAYA *et al.*, 1983). Connate sea water which introduced during the fjord age, seasalt particles and crustal weathering material are not a significant source for trace elements in Lake Vanda water.

Also the relationships of trace metal contents between the aerosol at the South Pole and the waters of the Canopus Pond, Lake Fryxell, Labyrinth L-4 Pond and Don Juan Pond are shown in Figs. 6, 7, 8 and 9, respectively. The chemical compositions of the Lake Fryxell and Canopus Pond waters show a good agreement with that of aerosol particle. The chemical compositions of the Don Juan Pond and Labyrinth L-4 Pond waters, however, show a poor agreement especially for Cs and

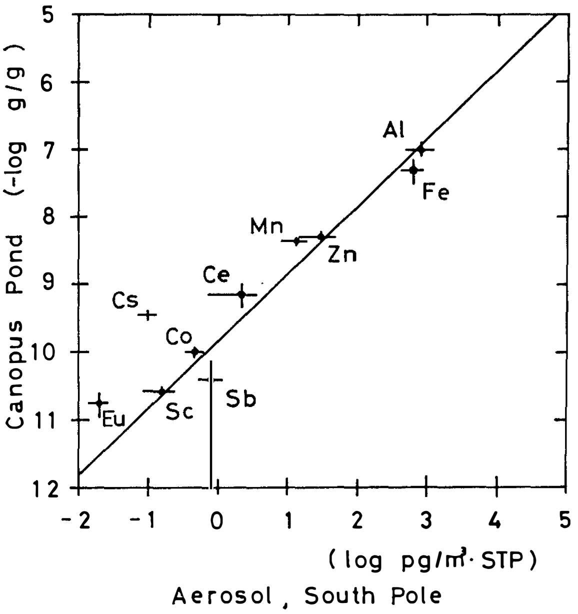


Fig. 6. Relationship of trace element contents between the Canopus Pond water and the South Pole aerosol particle.

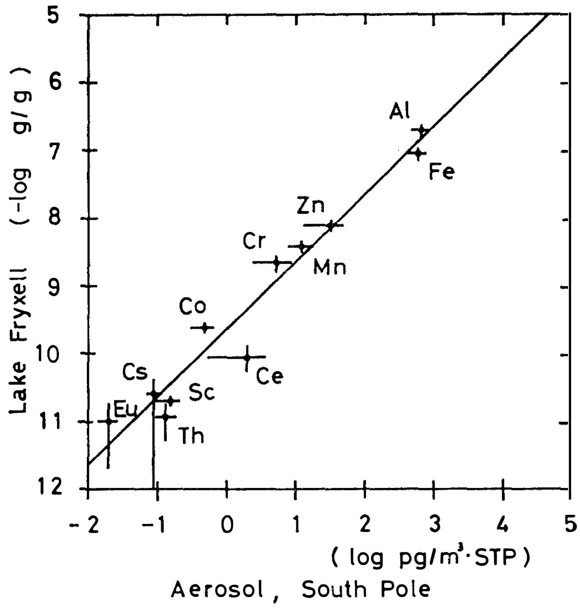


Fig. 7. Relationship of trace element contents between the Lake Fryxell water and the South Pole aerosol particle.

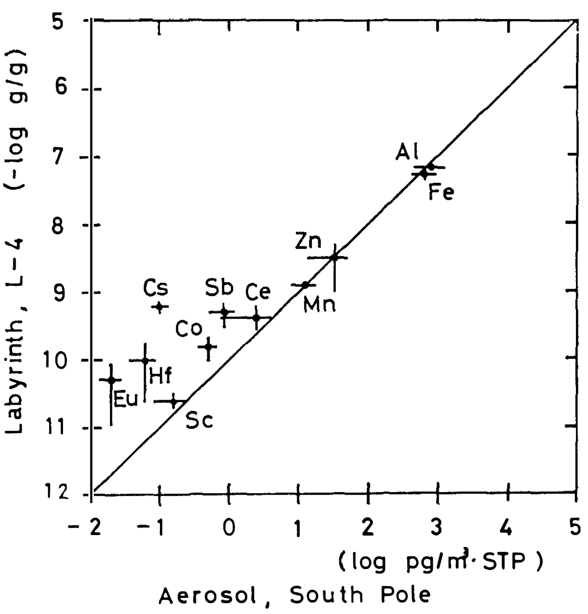


Fig. 8. Relationship of trace element contents between the water in Labyrinth L-4 Pond and the South Pole aerosol particle.

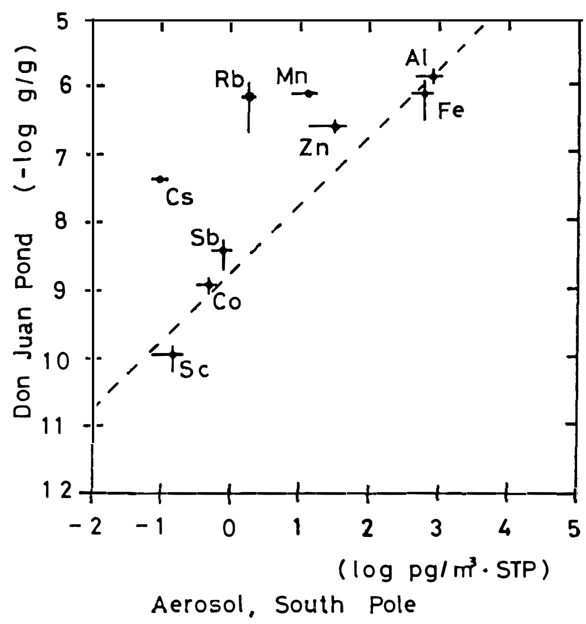


Fig. 9. Relationship of trace element contents between the Don Juan Pond water and the South Pole aerosol particle.

Rb. The water sample of L-4 Pond was collected in the 1978–79 austral summer season, but in the 1982–83 season the L-4 Pond water was dried up. This pond would have repeated the water flow–dry up cycle.

Cs (alkali metal) is easily dissolved when water flows in, whereas Al, Fe and Sc will not be dissolved from dried residue. Cs and Rb in the Don Juan Pond water are also anomalously enriched compared with the other elements (Fig. 9). This anomalous enrichment may suggest that the Don Juan Pond would have repeated a water flow–dry up cycle like the L-4 Pond, and then alkali and alkaline earth metals remained or were easily dissolved from dried residue or sediment. Al, Fe, Co and Sc seem to be precipitated and not to be dissolved into inflowing water because of their low solubility. This process should have been repeated to give the observed composition. Manganese is considered to be reduced in the sediment and to be diffused upward.

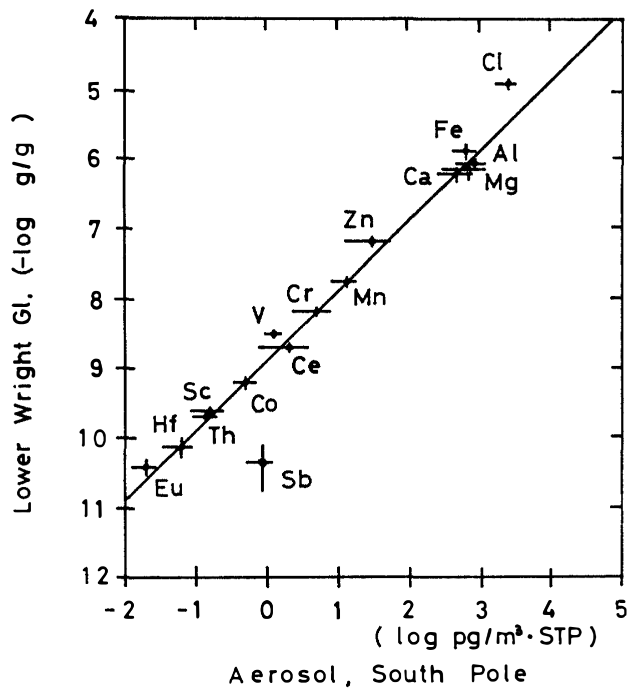


Fig. 10. Relationship of trace element contents between the Lower Wright Glacier ice and the South Pole aerosol particle.

A good correlation of the chemical composition between the Lower Wright Glacier ice and aerosol particle is shown in Fig. 10. The Lower Wright Glacier is a part of the Wilson Piedmont Glacier which is situated on the coast of the Ross Sea and the glacial melt water drains into the Onyx River. The good correlation supports the aerosol origin for trace elements in the Lake Vanda water. Chlorine enrichment in the Lower Wright Glacier ice compared with the South Pole aerosol is caused by the supply of sea spray. The ice sample of the glacier was collected at a terminus ice cliff (*ca.* 20 m high, sampling height 1.5 m) near the Lower Wright Hutt. The similar chemical compositions indicate that the chemical compositions of aerosol particles are not so different except for Cl^- between the Antarctic coast and the inland plateau, and that the present-day aerosol (South Pole) would have almost the same chemical composition at the time when the Lower Wright Glacier sample ice has precipitated. Chemical analyses of inland ice core samples will provide a more exact understanding of palaeo-aerosol composition.

The correlations of chemical constituents between the aerosol particle and the lake waters indicate that trace elements in the Antarctic saline lake waters might have been derived from aerosol particle.

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