Total Organic Carbon in Pond Waters from the Labyrinth of Southern Victoria Land in the Antarctic

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南極南ビクトリアランドのラビリンスにおける池水中の全有機炭素

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要旨：南極南ビクトリアランド・ライト谷上部のラビリンス (77°33′S, 165°50′E) に分布する，10 個の池の全有機炭素 (TOC) を測定した．TOC 値は池水間で大きく異なる (0.78–23 mgC/*l*) が，高濃度の TOC は塩池水のみで測定された．電気伝導度と TOC 値間には，かなり高い正の相関 (0.82) がみられた．このことは次のように解釈される．1) まず降雪や氷河融水に含まれていた有機物が，池水の凍結により残液に濃縮される．2) 次いで池内の生物生産による有機物が加わるとともに，容易に微生物分解を受ける有機物が除去される．3) さらに池水の蒸発と凍結が繰り返されることにより，長年月の間に比較的分解しにくい有機物が，溶存無機塩類とともに池底付近に蓄積される．

Abstract: Total organic carbon (TOC) in 10 freshwater and saline ponds in the Labyrinth (77°33′S, 160°50′E) of southern Victoria Land, Antarctica, was preliminary studied to clarify their distribution and sources. The TOC concentrations ranged from 0.78 to 23.1 mgC/*l*. The high TOC concentrations were found only in saline pond waters. The correlation coefficient between electric conductivity and TOC value was considerably high (0.82). This result can be explained as follows: Organic substances supplied from snow and glacial meltwaters are first concentrated in the residual pond waters by freezing out. Also *in situ* photosynthetic activity produces organic substances, but certain labile organic constituents may be degraded by microbial activity. Further, repeating freezing and evaporation of pond waters work to concentrate relatively refractory organic substances in the pond bottom waters, together with dissolved inorganic salts over a long period of time.

1. Introduction

There are a number of ice-free areas, so-called oases, in the coastal regions of Antarctica, where many lakes and ponds are distributed with various salt concentrations ranging from near snow meltwater to 13 times in magnitude greater than that of seawater (*e.g.*, MURAYAMA, 1977; BURTON, 1981; TORII and YAMAGATA, 1981). The concentrations of total organic carbon (TOC) and dissolved organic carbon (DOC) in Antarctic saline lake waters from the McMurdo, Syowa and Vestfold oases

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have been reported to be considerably high with the highest DOC value of 186 mgC/*l* (PARKER *et al.*, 1974, 1977; MATSUMOTO and HANYA, 1977; MATSUMOTO *et al.*, 1979, 1984, 1987a, 1987b; BARKER, 1980; HAND, 1980; BURTON, 1981; TOMINAGA and FUKUI, 1981). Generally, TOC or DOC concentrations in saline waters are much higher than those in freshwaters (MATSUMOTO, 1987). Interestingly, TOMINAGA and FUKUI (1981) reported a good correlation between DOC and chlorinity for Lakes Nurume, Suribati and Itiziku from the Syowa Oasis and suggested that the high DOC concentrations are due to concentration of organic substances in seawater during concentration of sea salts. So, the TOC concentrations in the inland areas, where no direct influence of seawater can be expected, are interesting in relation to organic carbon sources. Here we preliminary studied TOC in ponds of the inland areas, *i.e.* the Labyrinth of the upper Wright Valley of southern Victoria Land in Antarctica to characterize TOC concentrations and discuss organic carbon sources.

2. Materials and Methods

The Labyrinth, an extensive ice-free area with approximately 5.5 km width and 7 km length, lies at altitudes between 500 and 1000 m, and distant approximately 50 km from the coast (Fig. 1). The west end of the Labyrinth terminates with the Wright Upper Glacier. More than 60 ponds with various salt concentrations ranging, in chloride ion concentrations, from 0.0049 to 58.3 g/kg are distributed in the Labyrinth (MATSUMOTO *et al.*, 1985; TORII *et al.*, 1987). The ponds in the Labyrinth are small, mostly less than 100 m in diameter, shallow and generally covered perennially with ice, although edges of the ponds are melt in the austral summer. Dissolved inorganic salts are chiefly concentrated in the pond bottom underneath ice cover.

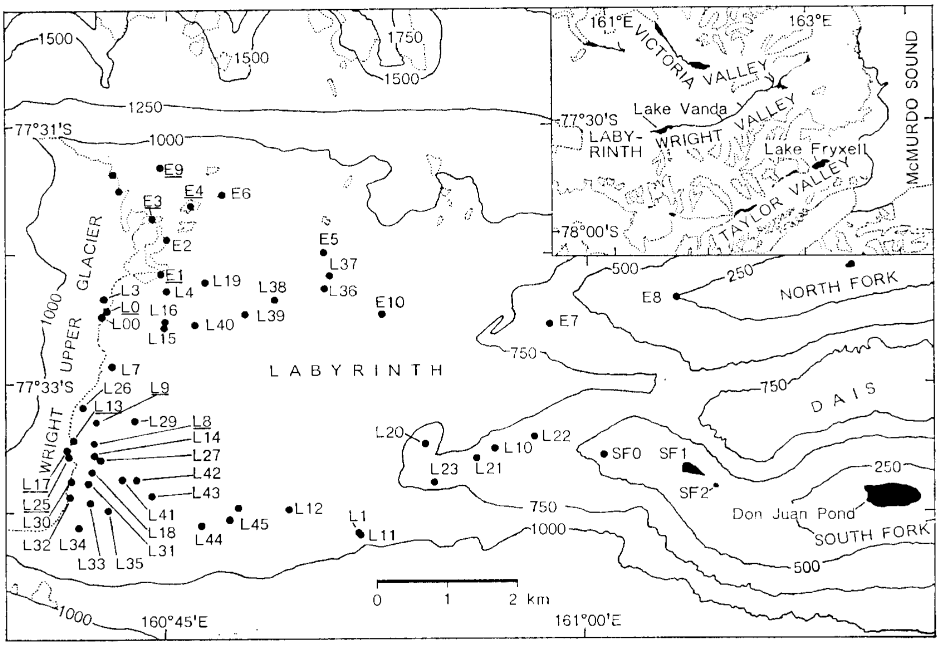

Fig. 1. Distribution of ponds in the Labyrinth of southern Victoria Land, Antarctica. TOC studied ponds were underlined.

After drilling into the pond ice using a SIPRE ice auger or breaking down the ice with an ice axe, pond water samples were collected using a hand-operated siphon and/or directly with 50 m*l* polyethylene bottles on 22–24 December 1985. Electric conductivity was measured *in situ* using a HORIBA DS7 electric conductivity meter. The sample bottles were kept frozen until analyzed. The TOC values were determined by a wet oxidation method (MENZEL and VACCARO, 1964).

3. Results

TOC concentrations of pond water samples from the Labyrinth are shown in Table 1, together with electric conductivity results. The TOC values in the pond water samples ranged broadly from 0.78 to 23.1 mgC/*l*. Higher TOC values were found in the L0-1 and E1 pond samples, which are much higher than those in the highly polluted urban Tama River waters (average, 7.6 mgC/*l* at Chofu) in Tokyo (MATSUMOTO and HANYA, 1981). However, they are similar to those in saline lake waters in the McMurdo, Syowa and Vestfold oases (*e.g.*, PARKER *et al.*, 1974; MATSUMOTO *et al.*, 1979; BURTON, 1981; TOMINAGA and FUKUI, 1981). It can be seen from Table 1 that the pond water containing the high TOC concentration also showed the high electric conductivity. So TOC concentrations of the pond water samples were plotted against electric conductivity results (Fig. 2). The regression of TOC on electric conductivity is represented as follows: TOC=0.36 (electric conductivity)+0.31 with a correlation coefficient of 0.82. This considerably high correlation coefficient may be related to the similar concentration processes of TOC and dissolved inorganic salts.

Table 1. TOC and electric conductivity results for pond waters from the Labyrinth of the upper Wright Valley in southern Victoria Land, Antarctica (sampling date: 22–24 December 1985).

Pond	Sampling depth (m)	Depth of sampling site (m)	TOC (mgC/*l*)	Electric conductivity (mS/cm at 25°C)	Pond type
L0-1	0.92	0.95	23.1	40	saline
L0-2	0.64	0.68	1.9	19	saline
L8	surface	*ca.* 0.1	2.9	6.4	saline
L9	0.40	0.45	3.9	24	saline
L13-S	0.83	0.86	7.7	9.6	saline
L17	1.38	1.41	0.78	0.12	fresh
L25	0.40*	>2	0.79	0.20	saline
E1	0.79	0.82	10.2	38	saline
E3	2.23	2.26	2.6	7.2	saline
E4	0.40	0.45	0.78	0.069	fresh
E9	0.73	*ca.* 1	0.81	1.0	fresh?
Inflow to E3**	surface	0.05	0.99	0.038	

*Puddle water.

**Meltstream from the Wright Upper Glacier.

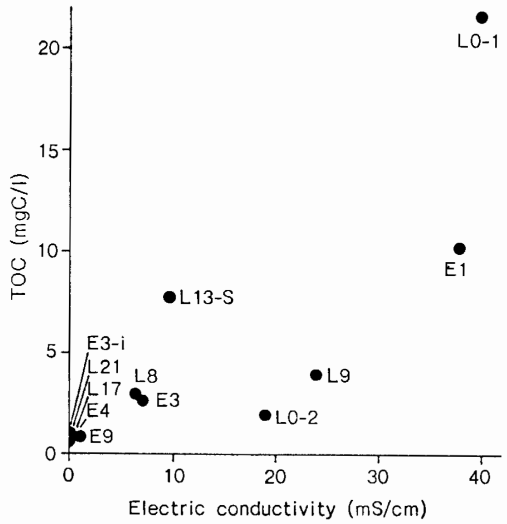

Fig. 2. Correlation between electric conductivity and TOC results for the Labyrinth pond waters. Correlation coefficient=0.82. E3-i: Inflow to E3 pond.

4. Discussion and Conclusion

The source and concentration of organic substances under frigid conditions will be discussed as follows: First, the concentration of organic substances in seawater as suggested for saline lakes in the Syowa Oasis (TOMINAGA and FUKUI, 1981); second, the concentration of organic substances in snow and/or glacial meltwaters; and third, *in situ* biological activity.

As noted above, the Labyrinth is located far from the coast at high altitudes. Most of freshwater and saline ponds in the Labyrinth have no outflow. Chemical compositions of major ionic components (Na^+, K^+, Mg^{2+}, Ca^{2+}, Cl^- and SO_4^{2-}) in pond waters in the Labyrinth are generally similar to those of lakes and ponds in the Dry Valleys (TORII *et al.*, 1987). TORII *et al.* (1987) reported that dissolved inorganic salts in the pond waters in the Labyrinth can be explained principally by the accumulation of atmospheric salts. That is, freshwaters originated from glacial and snow meltwaters in which the chemical composition gradually approached to that of the saline ponds under frigid conditions by repeating freezing and evaporation. Further, for the formation of a saline pond (L1, Fig. 1) in the Labyrinth containing sodium ions of 4.13 g/kg (2.6 times in magnitude greater than that of seawater), TORII and YAMAGATA (1981) estimated the possible age of the pond from the difference in sodium ion concentration between snow and pond water, and obtained 56000 years. Thus the ages of the ponds in the Labyrinth can be expected to be much younger than 1×10^5 years. These results indicate that inland saline ponds are easily formed through the accumulation of atmospheric salts. Therefore, the concentration of organic substances in seawater is unlikely.

DOWNES *et al.* (1986) reported that the DOC concentrations of glacier ice and fresh snow from the Dry Valleys are relatively high (0.8–2.8 mgC/*l*). Stable isotopic ratios, δD and $\delta^{18}O$, reveal that the E3 pond water is supplied from the Wright Upper

Glacier, while the L0, L9, L13 and L17 pond waters are mainly derived from local snow (TORII *et al.*, 1987). The L25 pond water should be fed mainly by the Wright Upper Glacier because the glacier ice directly falls into the pond. However, the L8, E1, E4 and E9 pond waters must be supplied from local snow, because these ponds are isolated from the Wright Upper Glacier. Hence, freshwater ponds can be expected to contain considerable amounts of organic carbon. Indeed, the TOC concentrations of the freshwater ponds are comparable with those of DOC concentrations of snow and glacial meltwaters (Table 1). This result reveals that snow and glacial meltwaters are important sources of organic substances in the Labyrinth ponds.

On the other hand, in and around the ponds there are cyanobacterial mats which produce organic substances during the austral summer through photosynthetic activity. In some ponds pH values rise greater than 10 by intense photosynthetic activity (MATSUMOTO *et al.*, 1985; TORII *et al.*, 1987). Thus *in situ* biological activity also must have contributed to the distribution of organic substances in the Labyrinth ponds.

Relatively high correlation between electric conductivity and TOC results can be explained as follows: The ponds studied were all frozen down to near the bottom, while edges of the ponds were melt in the austral summer. Thus it is much likely that organic substances were concentrated first in the residual waters by freezing out together with dissolved inorganic salts. Further, subsequent repeating evaporation and freezing of pond waters lead to concentration of organic substances in the residual pond waters during a long period of time as discussed above.

Therefore, the source and concentration of organic substances in pond waters of the Labyrinth are concluded as follows: Organic substances supplied from snow and glacial meltwaters were concentrated first by freezing. Also *in situ* photosynthetic activity produces organic substances, but certain labile organic constituents may be degraded by microbial activity. And subsequent repeating evaporation and freezing of pond waters further concentrate relatively refractory organic substances and dissolved inorganic salts in the residual pond waters during a long period of time.

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