RESEARCH ON SOLID PARTICLES IN RIVER ICE

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ABSTRACT

The authors have been conducting research on the contamination of ice and snow in Hokkaido, the northernmost island of Japan. In this report, we will focussed on the suspended solids (SS) in ice in rivers and lakes. We will report on the physical and chemical properties of ice floes by layer based on our investigation.

Ice floes were gathered from the lower section of the Teshio River, freshwater lake ice in Lake Barato, Lake Utonai, Lake Shuparo, and the Oikamanai swamp etc., and also from brackish-water lakes, such as Lake Abashiri, Notoro Lagoon and Saroma Lagoon.

River ice had three layers: from the top, the snow layer, snow ice layer and clear ice layer. The level of solid particles included in ice was largest in the surface layer. Then, they were gradually decreased toward the bottom of ice. The ice immediately under a bridge contained a high level of solid particles, which were gradually became less as farther from the bridge.

The most of solid particles were classified as silt form their median diameters. The chemical properties of ice floes was different from that of water under the ice because the levels of iron, such as Cl^- and So_4^{2-}, were high. In terms of mineral in general, the sample taken under a bridge had high alkalinity, from which we can estimate their contamination.

Lake ice also had similar properties. The level of solid particles became less as farther from roads. The level of solid particles in accumulated snow on ice was more than the twice of that of the ice at most research sites. Especially, the diameter of solid particles contained in ice were large at Barato Lake, where influence of heavy urban traffic was observed.

1. INTRODUCTION

Ice and snow not only serve as an enormous water resource and heatsink but also exert influence on the ecosystem and human culture. This is because ice and snow are basic components of the hydrologic cycle and the general circulation of the atmosphere. Therefore, it is presumed that extreme contamination of ice and snow will have a harmful influence upon the earth, not only on local environment on but also on a global scale.

At present, widespread negative effects on the environment have not been observed. Yet over a long-term period, it is feared that the ecosystem might change and abnormal weather may occur because air pollution varies the albedo of snow and promotes the melting of snow. Ice and snow are also considerably contaminated with oil from vehicles, grease, coarse particulates, household garbage (Tachibana. H., 1994), and deicing agents, etc. Therefore, some scholars say that there is a danger that river and subterranean water might be contaminated. Moreover, corrosion and abrasion of structures constructed on road, rivers, and coasts caused by pollutants in ice and snow has been reported in Japan (Hara. F., 1993). This report will cover the results of research and analysis on the physical and chemical properties by layer of ice floes, especially those in rivers and lakes.

The research was conducted at rivers and lakes in Hokkaido as shown in Fig. 1. Ice floes were gathered from the lower section of the Teshio River, freshwater lake ice in Lake Barato, Lake Utonai, Lake Shuparo, and the Oikamanai swamp etc., and also from brackish-water lakes, such as Lake Abashiri, Notoro Lagoon and Saroma Lagoon. The following indicates the results of analysis on these floes at each sampling site.

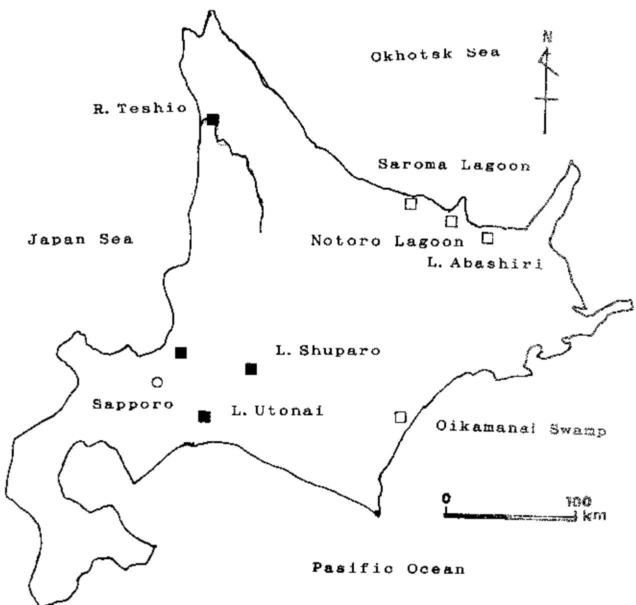

Fig. 1 Ice floe sampling sites

2. RESULTS OF THE ANALYSIS OF RIVER ICE

2.1 Outline of the Research

The research was carried out near the Teshio Ohashi Bridge, located 18.7 km from the mouth of the Teshio River (the total length of the trunk channel is 256 km, the fourth longest in Japan). As shown in Fig. 2, ice was sampled at seven sites between the bridge and a point 400 meters upstream. The survey was carried out from 3 to 6 p.m. on March 6, 1993. It was cloudy with the temperature being -0.2 °C, and the water temperature was 0.0 °C at that time. The sampling sites are completely frozen from January to March.

River ice samples were obtained by using an electric saw to cut through the surface ice to the water. The cuts at the surface were 50 cm by 50 cm. Snow at the survey areas was collected in 1 meter square wide areas after the snow depth height was measured. Ice was classified by layer and stored in a freezer in plastic bags after the measurement of thickness, etc. Ice samples were dissolved at room temperature. After the pH, conductivity (Cond.), and 4.3 Bx (Alkalinity) were measured, part of the water samples were filtered with a membrane filter (pore size: 0.45 μ) and preserved. In these circumstances, residual materials on the filter were measured for the solid particle levels. The solid particle contents are considered to be the amount of suspended solids within a fixed cubic volume of melted ice and is indicated by the unit of mg/l. General mineral elements were analyzed by the use of filtered samples. Solid particles were separated from the rest of the water samples by continuous centrifugation with a circulation of 18,000 rpm, and also by freeze-drying. Then solid particles were classified by particle size with a screen and Laser Microsizer (Seishin SK-7000). The Teshio River water was analyzed in the same way as the ice samples.

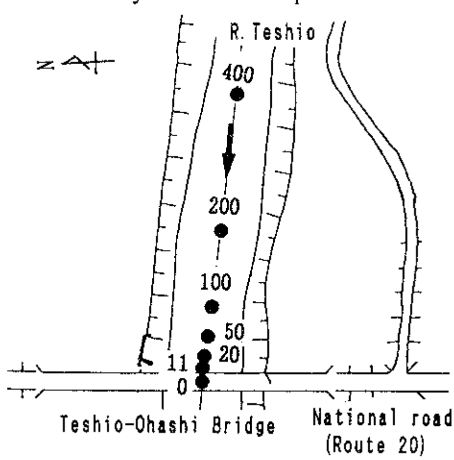

Fig. 2 Floe research sites
(Figures are the distance from the bridge (m))

2.2 Results and Discussion

(1) Condition of river ice

As is shown in the results of the research in Table 1, ice floes at the sampling sites were

Table 1 Properties of ice floe

Sample No.	↓ Distance(m) from the bridge		Density**	Thickness(cm) of floe	of layer cm	Solid *** matter mg/l	median diameter μm
1	0	Water				3.2	41.4
2	0	Snow	0.41	40	5.0	342.1	23
3	0	Snow-Ice*	0.83		15.0	353.4	29
4	0	Snow-Ice	0.83		20.0	24.1	18.6
5	11	Snow Ice	0.79	73	16.0	6.4	
6	11	Snow Ice	0.76		14.0	9.3	72.2
7	11	Snow Ice	0.67		15.0	8.7	44.4
8	11	Snow Ice	0.30		15.0	3.7	55.8
9	11	Snow Ice	0.57		13.0	10.4	18.3
10	20	Snow	0.80	53.5	1.5	47.4	14.8
11	20	Snow Ice	0.68		12.0	5.8	258
12	20	Snow Ice	0.36		18.0	3.9	46.6
13	20	Snow-Ice	0.34		9.0	3.8	
14	20	Snow Ice	0.79		13.0	6.9	63.3
15	50	Snow	0.60	47.5	1.5	86.2	
16	50	Snow Ice			9.0	5.7	
17	50	Snow Ice	0.73		8.0	3.5	
18	50	Snow Ice	0.83		9.0	2.6	
19	50	Snow Ice	0.86		20.0	4.4	
20	100	Snow	0.90	57	2.0	24.2	66.3
21	100	Snow Ice		Hard	8.0	4.1	21.5
22	100	Snow Ice	0.60		4.0	6.2	
23	100	Snow	0.36		9.0	42.8	13.6
24	100	Snow Ice		Hard	6.0	5.3	
25	100	Snow	0.40		6.0	6.3	
26	100	Snow Ice	0.63		9.0	2.8	
27	100	Snow Ice		Hard	13.0	6.2	16.1
28	200	Snow		50.5	4.0	11.4	
29	200	Snow Ice		49	10.0	6.1	27.6
30	200	Snow	0.58		16.0	6.1	
31	200	Snow Ice		Hard	17.0	5.6	
32	200	Snow Ice		Hard	6.0	2.9	17.8
33	400	Snow	0.74	46	3.0	4.5	14
34	400	Snow Ice		Hard	8.0	3.5	18.9
35	400	Snow	0.60		14.0	1.7	
36	400	Snow Ice	0.84		15.0	7	
37	400	Snow Ice		Hard	6.0	1.9	16.7

* i.d. a layer in which snow is solidified
** Hard:nealy 1
*** measured as the content in melted water

40 to 73 cm thick and had layers with different properties (Fig. 3). The snow layer was observed to be the surface layer composing some of the intermediate layer. Most of the ice sheet consisted of snow/white ice layers (a layer in which snow is solidified like ice) and thus it was proved that most of ice floes were made from snow. Clear ice was recognized only where it was in contact with river water. Table 2 is the chart of the thickness of ice according to each quality. The snow layer on the surface was as thin as 2.8 cm, whereas the thickness of other snow and snow ice layers was around 10 cm. Clear ice at the bottom layer was 6 cm thick, which was relatively thin. It was found that natural river ice had a stratiform structure, consisting of not a single layer but layers from several to scores of centimeters. It was found that river ice was composed of snow ice except for the clear ice at the bottom. Table 1 indicates the measured density of river ice. The density tended to be low in the snow layer and became higher in snow ice and clear ice layers.

Table 2 Thickness of floe layers

Layer		Numbers of samples n	Mean. cm	Max. cm	Min. cm
Snow	Surface	6	2.8	5.0	1.5
	in the ice sheet	4	11.3	16.2	6.0
Snow Ice*		24	12.3	20.0	4.0
Ice		2	6.0	6.0	6.0

* i.d. a layer in which snow is solidified

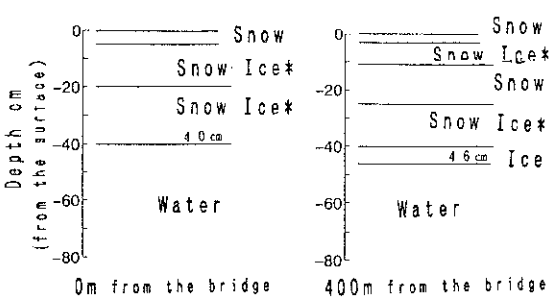

Fig. 3 Examples of the cross-sectional structure of floe

(2) Solid particle levels in river Ice

The solid particle level in river ice was high on the surface layer, while it was under 10 mg/l or so in the second and the third layers except at the 100-meter point. It can be conjectured that the content of solid particles on the surface become distributed uniformly during the period of the formation of the ice layer. The surface under the bridge contained a remarkably high 350 mg/l because of the accumulated road dusts from the road on the bridge. The exceptional example at the 100-meter point was probably due to the quality of snow and particle accumulation of road dusts. Solid particle content in the ice at the bottom layer was 1-2 mg/l, which was low. It shows that clear ice was formed by separating suspended solids from the water. The relation between the solid particle content and the distance from the bridge was indicated in regard to ice or snow in the surface layer (Fig. 4) and snow ice in the layer 10 to 20 cm below the surface (Fig. 5). The measured level of the solid particles was extremely high on the surface under the bridge and in the layer 10-20 cm below but declined dramatically farther away from the bridge. With regard to the 10-20 cm layer below the surface, the level was under 10mg/l at the 11-meter point and it had a tendency to drop gradually. It was found that road dusts heavily contaminate the ice near the bridge and that the solid particles blown by the winds were dispersed fairly far to affect the quality of ice though the degree of contamination is low.

Table 3 is the chart of the solid particle content by type of ice within the ice floe. Snow ice, or the major component of floes, contains approximately 5 mg/l of solid particles. This figure is identified to be lower than that of snow and much higher than that of ice.

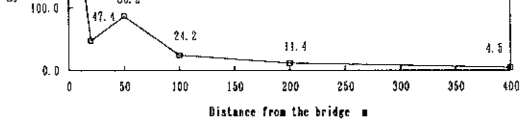

Fig. 4 Solid particle levels and the distance from the bridge (Surface layer, snow)

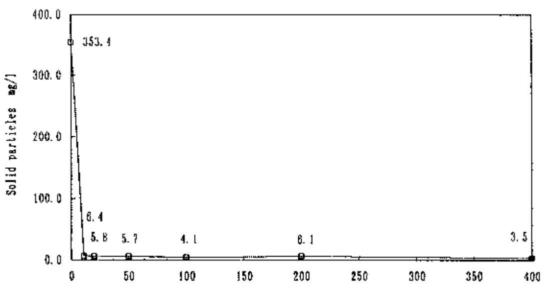

Fig. 5 Solid particle levels and the distance from the bridge
(10-20 cm layer below the surface, snow ice)

Table 3 Solid particles content of floe

Quality of ice	Numbers of samples	Mean. mg/l	Max. mg/l	Min. mg/l
Snow	4	14.2	42.8	1.7
Snow Ice	22	5.6	10.4	2.7
Ice	2	2.4	2.9	1.9

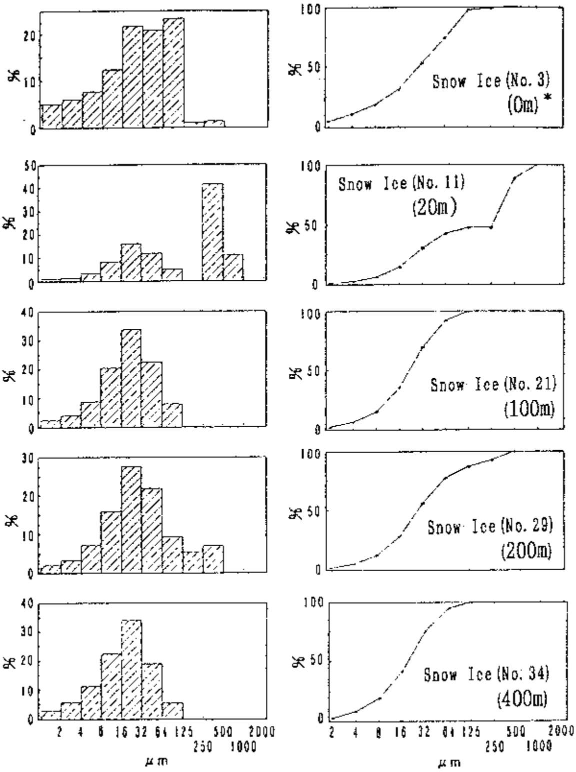

Fig. 6 Particle size distribution of solid particle
(10-20 cm layer below the surface, snow ice)

(3) Particle size distribution and median diameter values of solid particles

Judging from the median diameter values in Table 1, most of the solid particles of 20 samples were classified as silts which were smaller than 63 μm in size. Also, the median diameter values tended to diminish farther away from the bridge. Three samples at the 400-meter site had measured values under 20 μm. This is because very fine particles are likely to scatter far-away. This is also clear from the particle size distribution in the 10-20 cm layer below the surface in Fig. 6. The proportion of large solid particles, seemingly road dusts, was large under the bridge (0 meter). However, farther from the bridge, the median diameter values diminished and the distribution range narrows to a normal distribution. A large particle size of 268.2 μm, classified as fine sand, was observed at the 20-meter point. It was obvious that sand was intermixed as shown in particle size distribution. The cause, however, is not known.

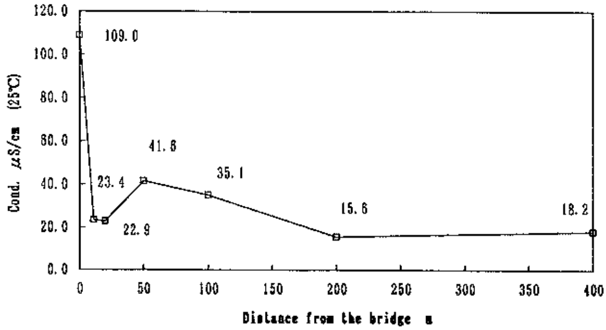

Fig. 7 Conductivity and the distance from the bridge (Surface layer, snow)

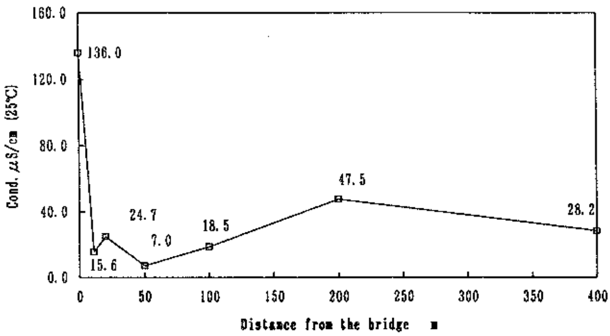

Fig. 8 Solid particle levels and the distance from the bridge (10-20 cm layer below the surface, snow ice)

(4) Chemical composition of river ice

The relation between conductivity and the distance from the bridge was charted in regard to ice or snow on the surface (Fig. 7) and snow ice in the 10-20 cm layer below the surface (Fig. 8). Influences by road pollutants were indicated in the composition of dissolved substances as well as in solid particles. Concerning the relation of conductivity and Cl^-, SO_4^{2-}, and 4.3 Bx shown in Fig. 9-1～3, it was clear that there was a high ratio of 4.3 Bx in the floe compared with water (◎). In other words, floe had a different chemical composition from water in which various substances were dissolved. Heterogeneous material, which seemed to be carbonate, was intermixed with the heavily contaminated floe. Conductivity was correlated with total anion concentration, or equivalent concentration, and served as an indicator of the amount of dissolved ions (Fig. 9-4).

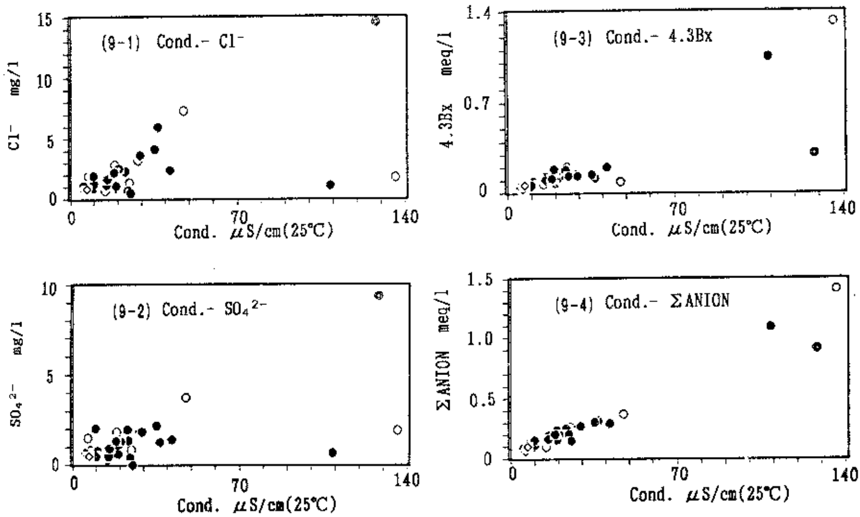

Fig. 9 The relation between conductivity and anion concentration
(○: snow, ●: snow ice, ◎: Teshio river water)

Table 4 Chemical composition of floe

Quality of ice		Cond. μS/cm	pH	Cl^- mg/l	SO_4^{2-} mg/l	4.3Bx meq/l
Water		128.0	6.9	14.5	9.4	0.306
(The data under the bridge)						
Snow (the surface)		136.0	7.3	1.8	1.9	1.319
Snow Ice (5-20cm below the surface)		109.0	7.5	1.1	0.7	1.046
Snow Ice (20-40cm below the surface))		19.0	6.2	1.0	1.1	0.187
(Excluding the data under the bridge)						
Snow (the surface)	Mean.	25.2	6.2	3.3	1.8	0.116
n=5	Max.	47.5	6.5	7.3	3.7	0.208
	Min.	7.0	5.8	1.4	0.8	0.055
Snow (floe)	Mean.	12.1	5.8	1.5	1.0	0.058
n=4	Max.	19.6	6.0	2.2	1.5	0.085
	Min.	6.3	5.7	0.7	0.3	0.030
Snow Ice (floe)	Mean.	18.9	6.0	1.9	1.0	0.110
n=22	Max.	41.6	6.5	6.0	2.2	0.200
	Min.	5.2	5.3	0.5	0.0	0.047
Ice	Ave.	6.6	5.7	0.8	0.5	0.047
n=2	Max.	7.0	5.8	0.8	0.5	0.064
	Min.	6.2	5.7	0.7	0.5	0.030

We summarized the chemical compositions of the ice floes in Table 4, according to each type of ice in consideration of the above mentioned characteristics. The conductivity of heavily contaminated floes was over 100 μs/cm, which was corresponded to the high level of 4.3Bx. The average value of the conductivity was between 10 and 20 μs/cm for snow and snow ice, and it was 10 μs/cm and below for clear ice. Moreover, it was noticed that Cl^- and SO_4^{2-} ions in floes including the contaminated one were remarkably lower in concentration than river water. As stated above, the chemical composition of anions, or equivalent ratio (Table 5), proves that the composition of the floe generally differs from that of water, holding a high percentage of 4.3 Bx in anion, especially in the contaminated floe, sometimes reaching 90%.

Table 5 Anion composition of floe

Quality of ice	Cl^- %	SO_4^{2-} %	4.3Bx %
Water	45.0	21.4	33.6
(The data under the bridge)			
Snow (the surface)	3.6	2.8	93.6
Snow Ice (5-20cm below the surface)	2.9	1.3	95.9
Snow Ice (20-40cm below the surface)	11.7	9.2	79.0
(Excluding the data under the bridge, Mean value*)			
Snow (the surface)	37.4	14.7	47.9
Snow (floe)	34.9	17.4	47.7
Snow Ice (floe)	28.4	11.1	60.5
Ice	28.5	14.1	57.3

* Numbers of samples: See Table 4

3. RESULTS OF THE ANALYSIS OF LAKE ICE

The research was conducted on the physical properties of solid particles in lake floes of both freshwater and brackish-water lakes in Hokkaido. Table 6 (on freshwater lakes) and Table 7 (on brackish-water lakes) demonstrate solid particle levels and median diameter values from the results of the research carried out from March 20 to 23 in 1989 and February 16 to 20 in 1990.

3.1 Floes of Freshwater Lakes

The levels of solid particles in the snow and ice of Lake Barato and Lake Utonai decreased farther away from the shores, and were obviously influenced by the mix of road dusts from roads. In one site in particular, the level at 5-meters from the shore of Lake Barato was recorded as 418 mg/l, which indicates a high risk of abrasion of underwater structures (Takahashi et al., 1990). The density of the solid particles within snow on the ice was high, and it was more than double the level within ice in most of the research sites, except Lake Shuparo. It is presumed that road dusts are contained within the snow that falls. It should be noted that the solid particles contained within the snow were transported to ice. Also, the density of suspended solids in water was lower than that of snow and ice, producing little effect on the levels within the ice excluding the case of the Oikamenai Swamp. In regard to particle sizes, the median diameter value of 203 μm was classified as a fine grain sand within the ice at a distance of 5-meters from the shore of Lake Barato, where a great influence from urban traffic was observed. Particle sizes at other research sites were in the range of silts. Coarse particles dusts which scattered far away were considered to consist of relatively small particles with the median diameter value being 5~20 μm. (Fig. 10-1--5 are the graphs of particle size distribution at the major research sites at Lake Barato.)

Table 6 Solid particle contents and median diameter values (freshwater area)

Name	Distance (m) from the shore	Sample	Solid particles (mg/l)	Median diameter (μm)
L. Barato	5m	Ice	418.0	203
	5m	Water	71.5	11
	20m	Ice	14.2	18
	20m	Snow	58.3	6
	50m	Ice	17.1	16
	50m	Snow	36.0	7
	50m	Water	5.0	15
L. Utonai	0m	Snow	1274.0	17
	10m	Ice	75.7	23
	10m	Ice	54.7	17
	30m	Ice	163.0	10
	30m	Ice	86.6	16
	60m	Ice	145.0	24
	100m	Ice	41.5	10
	100m	Water	1.8	19
	200m	Ice	20.1	13
	200m	Snow	174.0	14
	300m	Ice	22.7	12
	300m	Snow	114.0	7
L. Shuparo	20m	Ice	64.6	12
	20m	Snow	20.0	10
	20m	Water	10.7	24
Oikamanai Swamp	20m	Ice	27.7	15
	20m	Water	34.4	10

3.2 Floes of Brackish-water Lakes

Solid particle levels in ice diminish farther away from the shore, like the results of freshwater lakes. In the case of Lake Abashiri, the density was quite low at 200-meter from the shore. However, a fairly high solid particle level of 53.2 mg/l was detected in the snow at the 200-meter site of Lake Abashiri. Attention must be paid to the influence of this high level of contamination within snow on the level within ice.

The density of suspended solids within the water gets higher near the shore but was considerably low, compared to that within ice. The distribution pattern of the median

Table 7 Solid particle contents and median diameter values (brackish-water area)

Name	Distance (m) from the shore	Sample	Solid particles (mg/l)	Median diameter (μm)
L. Abashiri	20m	Ice	75.9	154
	100m	Ice	26.5	125
	100m	Water	3.3	24
	200m	Ice	9.0	18
	200m	Snow	53.2	31
	200m	Water	1.5	19
Notoro Lagoon	500m	Ice	12.5	8
	500m	Water	13.1	6
Saroma Lagoon	5m	Ice	95.5	21
	5m	Water	15.7	13
	50m	Ice	92.7	16
	100m	Ice	10.1	13
	200m	Ice	6.3	11

diameter values was almost the same as that of freshwater lakes. Large particles, such as those with size of 154 μm (classified as fine grain sand) and 125 μm (classified as particulate sand) which were produced and dispersed on roads were observed at sites 20 m and 100 m from the shore. (The graphs of particle size ditribution at the major research sites in Lake Abashiri are represented in Fig. 11-1--3).

The characteristics of the distribution of solid particles from the shore of lake Abashiri are as follows: Fig. 12 represents the distribution of solid particle levels in relation to the distance from the road near the shore. The shore was located 25 m from the road. Snow had the highest contamination levels, followed by ice, then water. Contamination of snow ice had a distribution range of 10.5--69.4 mg/l, whereas the density in water was 2.4--6.5 mg/l, which was quite low. That means a large quantity of solid particles were contained in snow ice as pollutants. The level near the shore was especially high, and was largely affected by the dispersal of road dusts around the road. Yet, considering the fact that black and dirty snow was gathered at a point 425--625-meter from the shore with a measurement of 121.4 mg/l, the high density in the snow at the 425-meter point was presumably caused by an artificial scattering or disposal of pollutants on ice. The high density level at the point 200-meters from the shore of Lake Abashiri (Table 7) was probably due to the same reason.

4. THE LEVEL AND COMPOSITION OF HEAVY METALS IN SOLID PARTICLES

Various information on contamination types and processes of ice formation can be obtained through the examination of the content and composition of heavy metals in

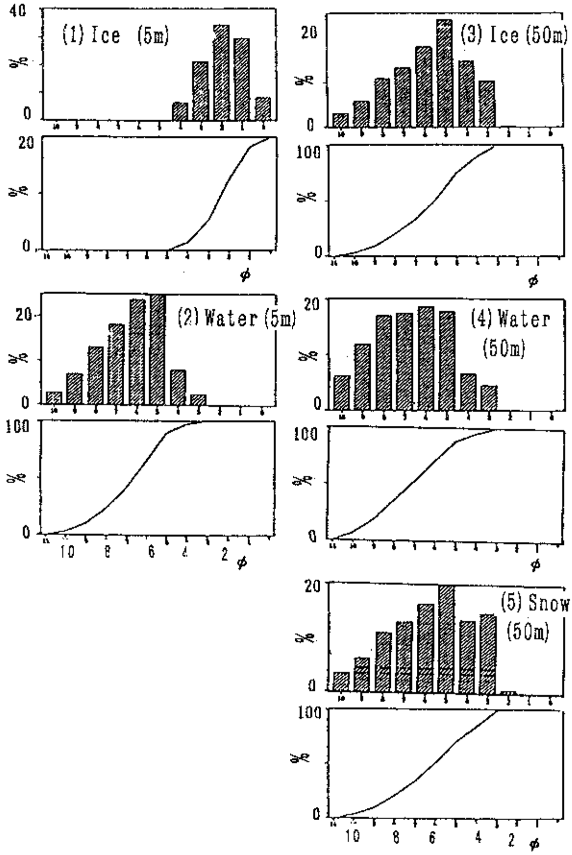

Fig. 10 Particle size distribution of solid particle levels at Lake Barato

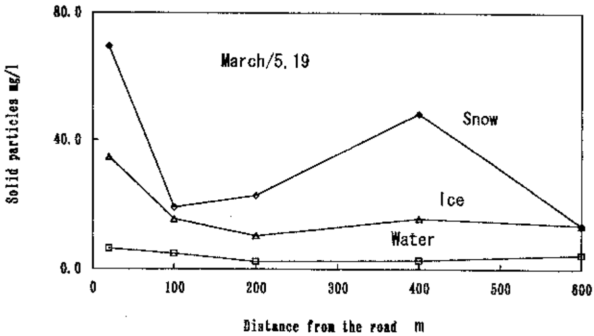

Fig. 12 Distribution of solid particle contents at Lake Abashiri

solid particles. We focused here upon iron, zinc and manganese and made some observations based upon their contents and compositions. The total content of heavy metals was extracted by Hydrogen Floride (HF) treatment and the content of artificial origin was extracted by HCL treatment. Table 8 is a summary of the contents of extracted heavy metals. Fig. 13 demonstrates HCL extraction versus HF extraction in terms of the average values of the samples. If these values are large, a high percentage of heavy metals of artificial origin, namely acid-soluble, are contained. The research was conducted at selected sites, such as Lake Abashiri, Lake Utonai, and the Teshio River from March 24 to 26 in 1991.

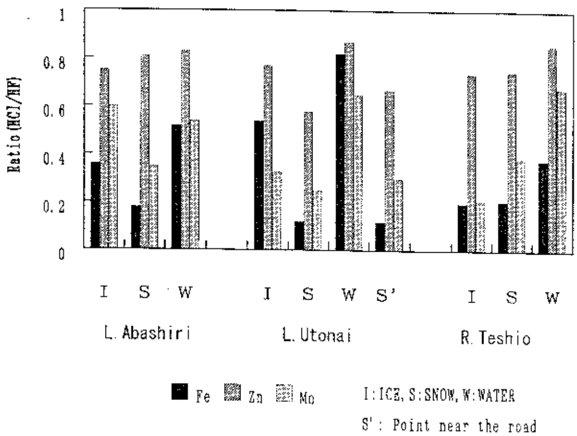

Fig. 13 Composition of heavy metals in solid particle contents in ice, snow, and water

When the levels of heavy metals in solid particles were compared to one another by means of the HF extracted components, there was little difference in the properties of the samples (ice, snow and water). The levels of heavy metals were somewhat higher in the water samples though there was little difference among sampling areas. However, by examining the percentage of components of artificial origin (HCL extraction, HF extraction), it was shown that the highest levels were in water, followed by ice and the lowest were in snow. Also, the compositions of heavy metals varied depending upon the properties of samples. It was obvious that the solid particles in water contained a high percentage of components of an artificial origin and those in snow contain a high percentage of components of a natural origin. Ice had an intermediate property between snow and water but closer to snow. This corresponds to the fact that ice in lakes and rivers is formed by snow, and shown in the example of the Teshio River. When compared in terms of types of heavy metals, zinc showed the highest level of components of an artificial origin. On the other hand, iron varied considerably in form within samples with different properties (ice, snow and water). It is apparent that water has a high level of components of an artificial origin and snow has a high level of components of a natural origin. Consequently, it is concluded that properties of solid particles vary according to the differing properties of samples. In other words, they differ in origins of solid particles.

5. CONCLUSION

The physical and chemical compositions of floes in rivers and lakes proved influences of environmental pollution. The results of this research are as follows:

Rivers: results of the research at the Teshio River

- The river floes were composed of layers which from the surface down were in the order of snow, snow ice, and clear ice. Each layer varies in thickness from several to scores of centimeters.
- The solid particle level in floes was high under the bridge due to contamination by vehicles, etc., and became lower farther from the bridge. The level in the floes was low: around 5 mg/l in the second layer (snow ice) and 1--2 mg/l in the third layer (clear ice), while it was higher in the deposited snow on the surface compared to ice floes.
- The median diameter value of the solid particles was under the size of silts and became smaller farther from the bridge. Many sandy particles were found under the bridge.
- --The floes had a lower density of Cl^- and SO_4^{2-} ions than water and differ in chemical composition.
- The alkalinity of general mineral elements was considerably high under the bridge, proving the influence of contamination.

Lakes:

- Like the case in the rivers, solid particle levels decreased farther from the shore. An obvious influence of the scattering of road dusts was observed.
- The solid particle level in floes at the shore of Lake Barato, where the traffic is particularly busy, was measured to have the unusually high value of 418 mg/l. The median diameter value was as large as 203 μ, which is classified as fine grain sand.
- Solid particles within the accumulated snow on floes were more than double the level contained in the floes in most sites except Lake Shuparo. It is possible that the solid particles in snow are transferred to the floes.
- The level of solid particles in the water under floes was low compared

The Level and Composition of Heavy Metals in Solid Particles:

- Results of the analysis on solid particles in ice floes are as follows: many of the heavy metals included in solid particles in ice floes, especially in a snow layer within the ice floe, had natural origins in comparison with those in water. The proportion of those with artificial origins tended to be high in zinc and low in iron.

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