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Measurements and Analyses of Aerosol Particles in Arctic Canada

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Abstract

The number concentrations of aerosol particles in five size ranges were measured for one month at Inuvik, Northwest Territories, Canada, using a particle counter. The number concentration changed depending mainly on the wind direction, stratification and human activity.

At the same time, aerosol particles were collected on Millipore filter papers using a newly developed aerosol sampler. Chemical components included in individual particles were analyzed by means of a scanning electron microscope and an energy dispersive X-ray microanalyzer. Chemical components changed also depending upon meteorological conditions and human activity. The origin of individual particles was considered from the wind field.

1. Introduction

In the Arctic area, investigations on aerosol particles have not been done sufficiently in comparison with temperate and subtropical areas.

Attentions have been focussed on air pollution in the Arctic area with the increase of the pollutants. According to the observations by Rahn et al. (1977), Barrie et al. (1981), Ottar (1981), Rahn (1981) and Leaitch et al. (1984), the Arctic area is polluted by aerosol particles which are transported from midlatitudes (Asia, North America and Europe). Rosen et al. (1981) reported a sudden increase of graphitic carbon attributed to anthropogenic activity and this increase was considered to lead to the phenomenon of the so-called Arctic haze. Lannefors et al. (1983) surveyed Norwegian regions of the Arctic, and they analyzed the chemical components of the aerosol particles using a PIXE.

In order to clarify the actual conditions of the Arctic haze, Arctic Gas and Aerosol Sampling Program (AGASP) was carried out. In this program, measurements were made at Barrow, Alaska, U.S.A., by Hansen and Rosen (1984), Lazrus (1984) and Radke (1984), at Alart, N.W.T., Canada by Hoff and Trivett

(1984) and at Resolute, N.W.T., Canada by McGuffie (1985).

At Inuvik, N.W.T., Canada, on the other hand, measurements of aerosol particles were made firstly by Kikuchi et al. (1978), however, they measured only the total number concentrations of aerosol particles, using a Gardner Counter. In the present observation, therefore, the number concentrations of aerosol particles in five size ranges were measured automatically and continuously for one month using a particle counter. Furthermore, chemical components included in individual aerosol particles were analyzed by means of a scanning electron microscope and an energy dispersive X-ray microanalyzer.

2. Measuring equipments

2.1 Measurements of the number concentration of aerosol particles

As the equipment for the measurements of the number concentration of aerosol particles, a particle counter (Type KC-01A) made by Rion Co. Ltd., in Japan was selected which can obtain size spectrum of aerosol particles automatically. The particle counter leads the air through a guided path, and when the aerosol particles cross a light beam, individual particles are detected. And at the same time, their diameters are measured by a photomultiplier followed by a pulse height analyser. The diameter of aerosol particles was divided into five size ranges, namely, 0.3 μm<, 0.5 μm<, 1 μm<, 2 μm< and 5 μm<, respectively, and the number concentrations of individual size ranges within the sampled air are displayed, then they are printed out by a digital printer.

The sampling volume of the air was adjusted to 10 liters which took 20 minutes for a complete measurement. Therefore, the size spectra of aerosol particles were obtained continuously at 20 minutes intervals.

2.2 Collection of aerosol samples

In order to collect aerosol particles automatically, a new continuous aerosol sampler as shown in Figs. 1 and 2 was developed. A rough outline of the mechanism of the aerosol sampler is described as follows: A Millipore filter paper of 90 mm in diameter is mounted on a small turn table. An off center part of the filter paper is located between an inlet pipe and a suction pipe as shown in Fig. 2. The diameter of both pipes is the same size of 11 mm. The outer air enters through the inlet pipe, and the aerosol particles included in the air settle on the upper surface of the filter paper. After a continuous suction of the air is carried out for one hour, the suction pump is stopped. After that the inlet pipe is lifted by a solenoid, and both pipes are released from the filter paper.

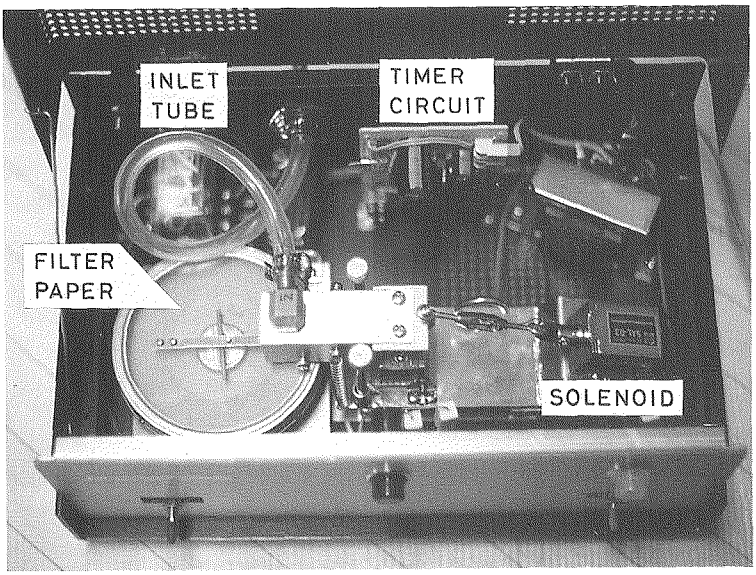


Fig. 1 A plan view of the continuous aerosol sampler.

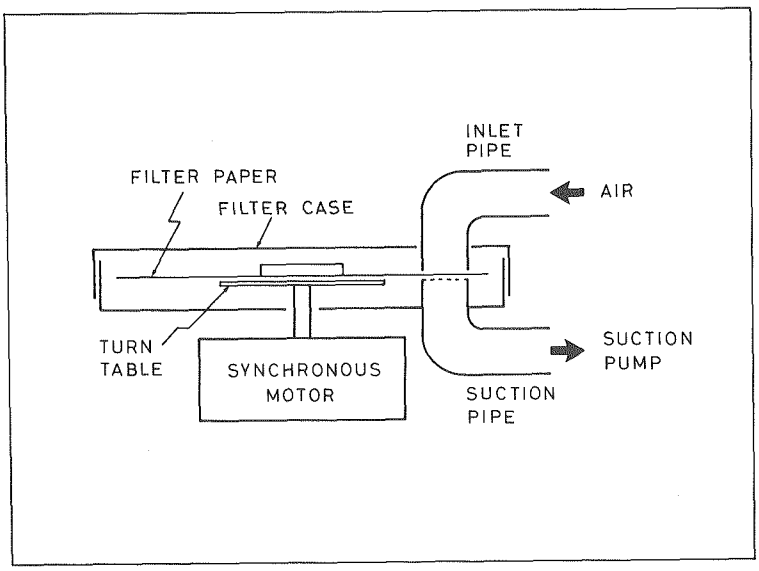


Fig. 2 The mechanical part of the continuous aerosol sampler.

Then the turn table supporting the filter paper is rotated to the next position by a synchronous motor. When the filter paper is rotated about 25 degrees, both pipes grasp the next position of the filter paper, and the suction pump resumes its work again.

By this continuous operation, twelve patches of hourly sampling of the aerosol particles were obtained on a filter paper automatically. Thus, the filter papers were changed twice a day. In the present measurement, a total volume of the air of approximately 120 liters containing the aerosol particles was collected on individual patches of filter papers. The total weight of this sampler is only 4 kg, and the weight of the suction pump is 2 kg approximately.

This apparatus has the following advantages; a tight sealing case such as used in the impactor method used by Leaitch et al. (1984) is not required. As a result, it is easy to operate even under low temperature conditions such as in wintertime in the Arctic areas. Furthermore, it can be used at a certain flow rate, thus it is possible to adjust the flow rate depending on the degrees of polluted air. Therefore, it can collect many particles effectively compared with the electrostatic precipitator method used by Bigg (1980). Because of the light and simple mechanisms, the sampler is useful for the tethered balloon observations.

3. Location of measurements

Measurements were carried out in a residential house area which was located at the east end of the town of Inuvik (68°22′N, 133°42′W), N.W.T., in the Arctic Canada as shown in Fig. 3. This town is located far 90 km inland from the Beaufort Sea. But, the sea surface is entirely covered with fresh sea ice and icebergs in winter seasons, so it is not possible to find any wide open water on the sea surface except for open leads. The population of this town is about four thousand, however, there are hardly any origins of smokes because they use electric power for heating and cooking in their everyday life. The particle counter and the aerosol sampler were set in a relatively cool room of the house in order to avoid large temperature differences between the sample air and the equipment. The outer air was drawn into the equipments through teflon tubes of 2 meters in length.

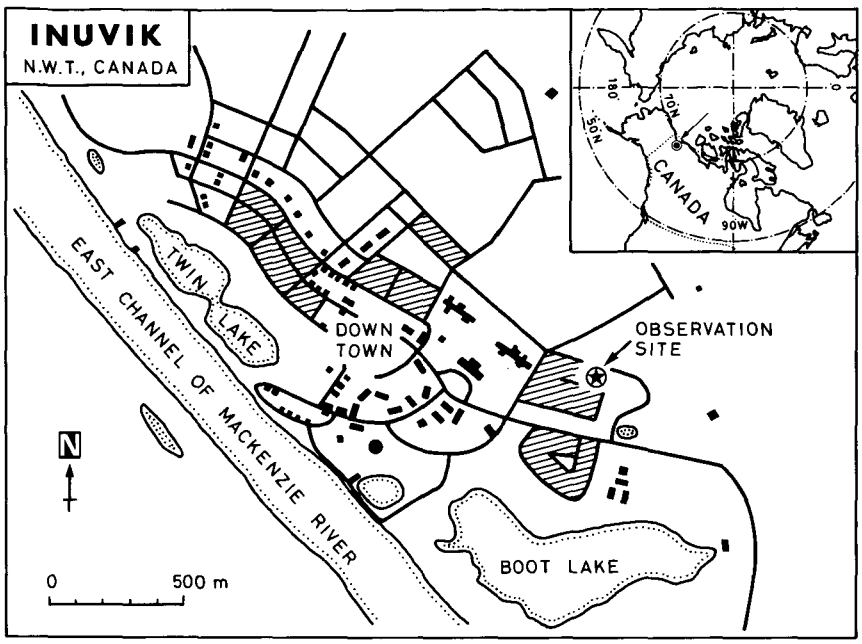


Fig. 3 Location of the observation site.

4. Results

4.1 Number concentrations of aerosol particles

The number concentrations of aerosol particles in five size ranges were measured from December 27, 1985 to January 24, 1986. Throughout this period, continuous data were obtained in spite of the very cold temperature conditions (The minimum temperature of the outdoors was about −47°C). The overall data are shown in Fig. 4. In this figure, the ordinate indicates the logarithms of the number concentration of aerosol particles per cm^3 of air, and the abscissa indicates the local mean time. The local mean time at Inuvik is 7 hours behind the Greenwich Standard Time, that is, 17 LMT, 24th means 00 GST, 25th December. The air temperature, wind direction and wind velocity shown in the figure were observed at the Inuvik airport which is located to 12 kms southeast from downtown Inuvik.

Diamond dust type ice crystals (ice prisms) and ice fog appeared frequently during this observation period, however, the amount of snowfall was very small. The stratification of the atmosphere had similar features in the nighttime as in the daytime, because of the weakness of the heating effect by solar radiation in

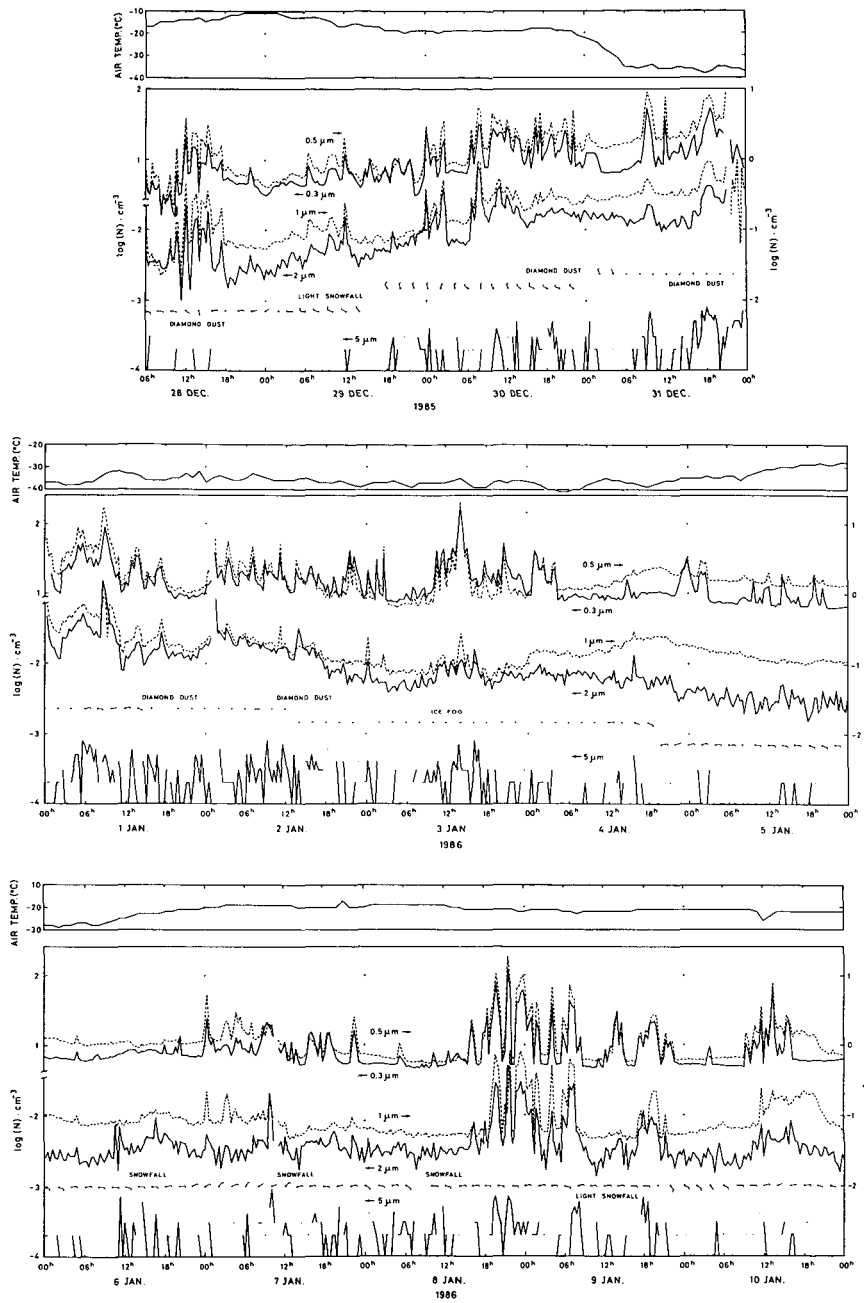


Fig. 4 Time changes of the number concentration of aerosol particles and meteorological conditions.

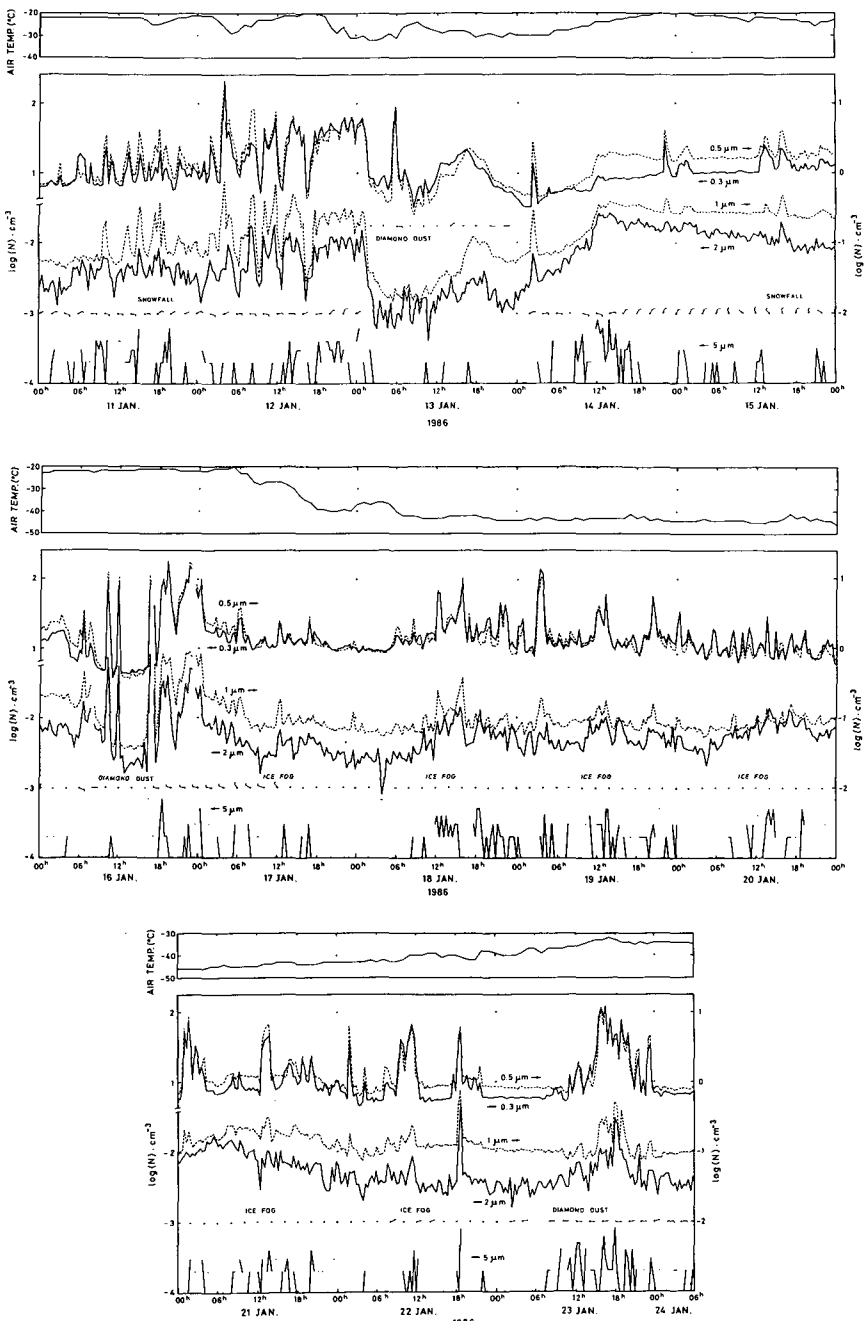


Fig. .4 (Continued).

the mid-winter seasons in the polar regions. Over a period of several days, some diurnal variations in the number concentration based on the human activity depending upon the wind directions were recognized. Some interesing cases will be discussed below.

Figure 5 shows a case when easterly wind was blowing constantly. This case may be a good example of the background aerosol around Arctic area because there was no anthropogenic origin of pollutant aerosols to the windward nearby. The number concentration of aerosol particles larger than 0.3 μm were approximately 10 particles per cm^3, and the concentration decreased by one order of magnitude as the particle size became two times larger. The number concentration of individual sizes show only a slight fluctuation, and the air temperature also did not show significant changes throughout the day. This

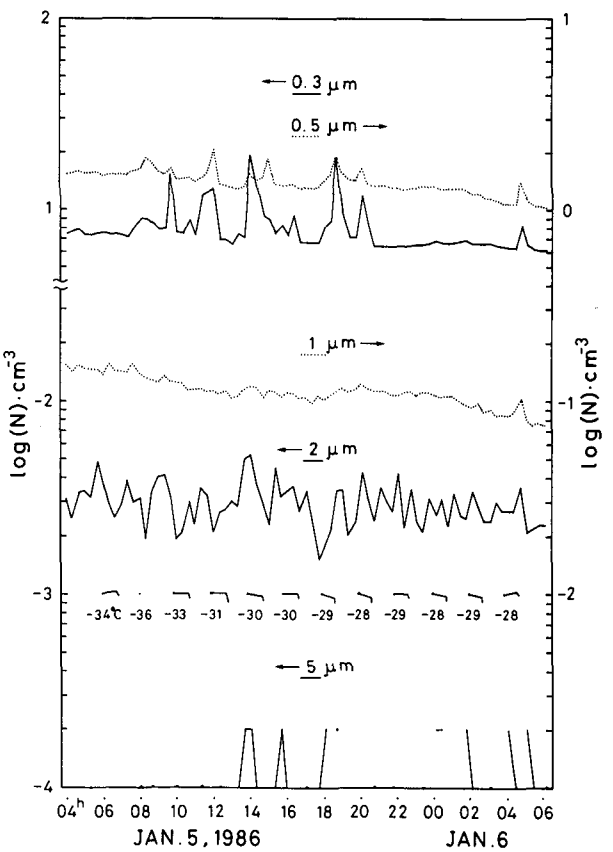


Fig. 5 An example of the time change of non-polluted day.

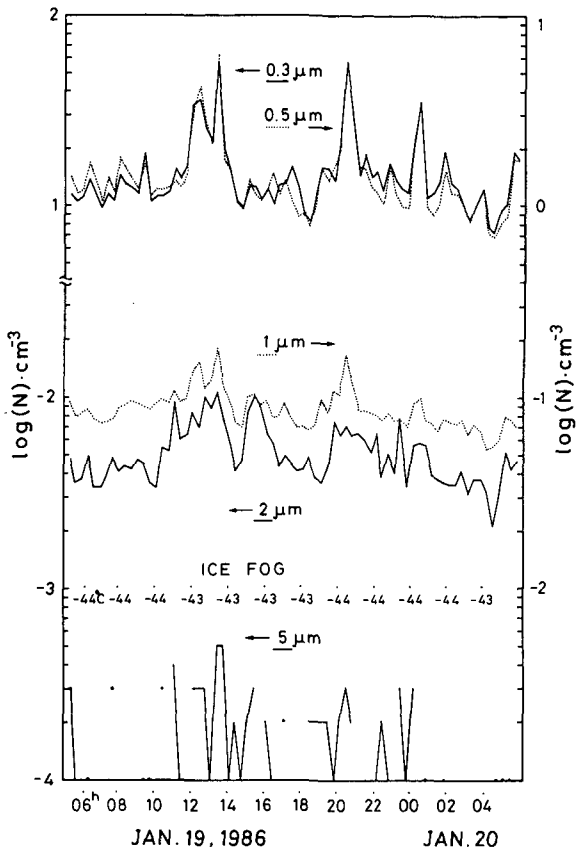


Fig. 6 An example of the time change of ice fog day.

suggests therefore that the observation site was covered by a uniform air mass for a considerable length of time. In addition, some effects by human activity can be seen around the daytime, but this effect was limited to a range of small size particles.

Figure 6 shows other case where the town was covered by a dense ice fog during 24 hrs more, and the wind was calm. Under such conditions, it may be presumed that the stratification of air above the ground surface nearby was in a strong surface inversion, and the number concentration remained steady. However, they represented considerable fluctuations that may be caused by the fact that the aerosol particles were distributed ununiformly depending upon an intensity of ice fog, and were drifting slowly.

The next case is shown in Fig. 7 when diamond dust type ice crystals were

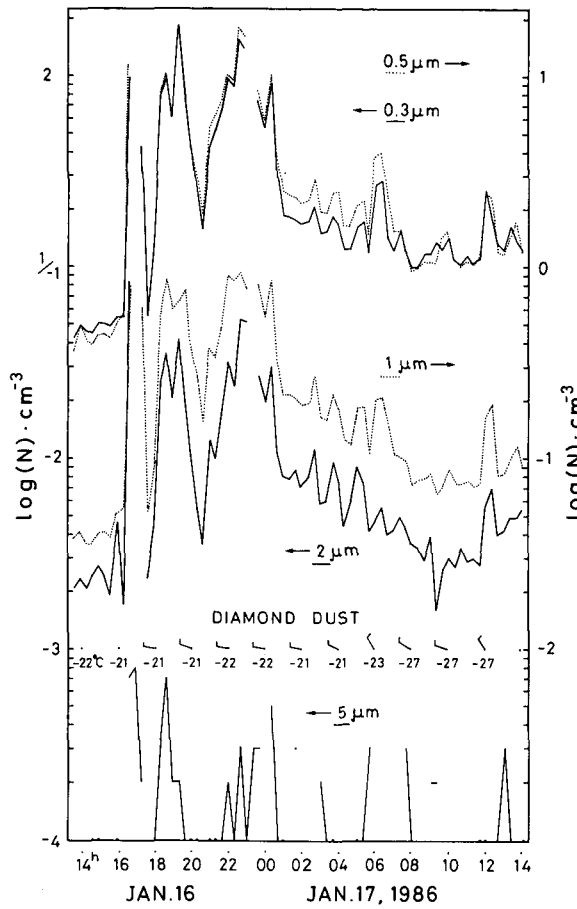
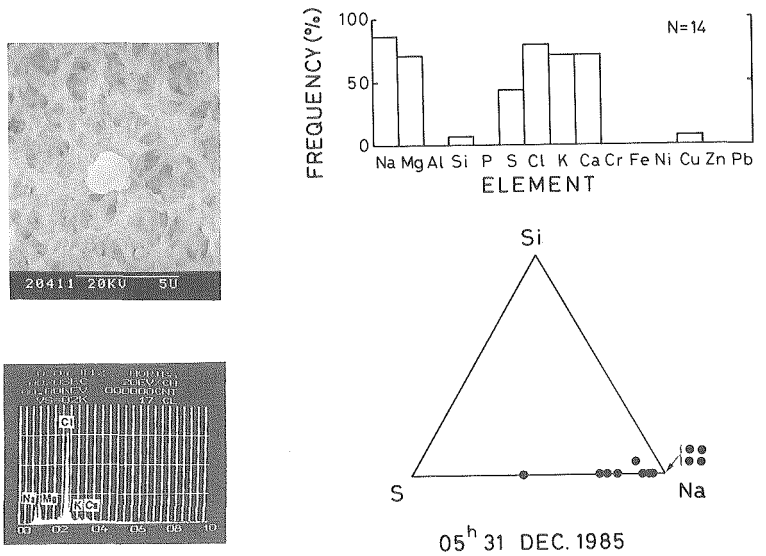


Fig. 7 An example of the time change of westerly wind day.

recognized and the wind was westerly. Before the midnight, the wind blew from the west, that is from downtown area to the observation site, and the number concentrations indicated high values. After that, as the wind direction changed to northwesterly, the number concentrations decreased gradually. This tendency was recognized in all size ranges except for particles larger than 5 μm in diameter.

4.2 Chemical components included in aerosol particles

Aerosol particles were collected on Millipore filter papers using a continuous aerosol sampler from December 23, 1985 to January 23, 1986. Although the



(a) (b)

Fig. 8 (a): SEM image of a particle (upper) and chemical components included in this particle (lower). Horizontal bar indicates 5 μm.
(b): Frequency of detection for each elements (upper) and triangular diagram of the typical three elements of Si, Na and S (lower).

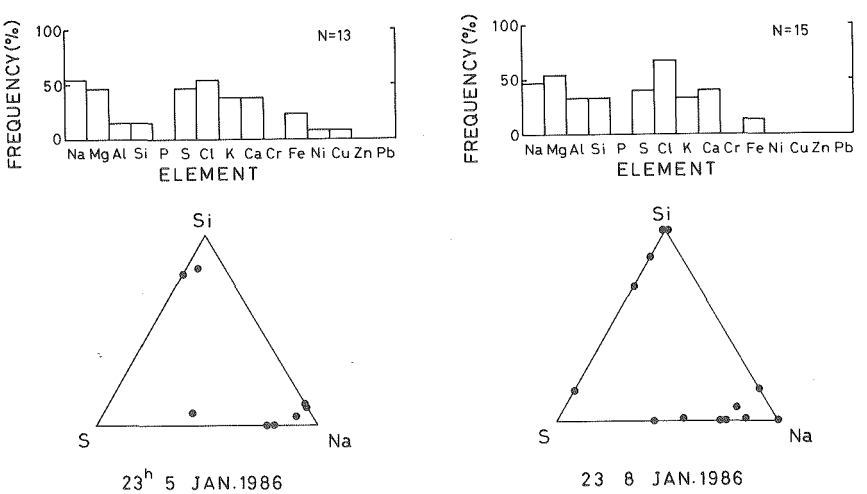
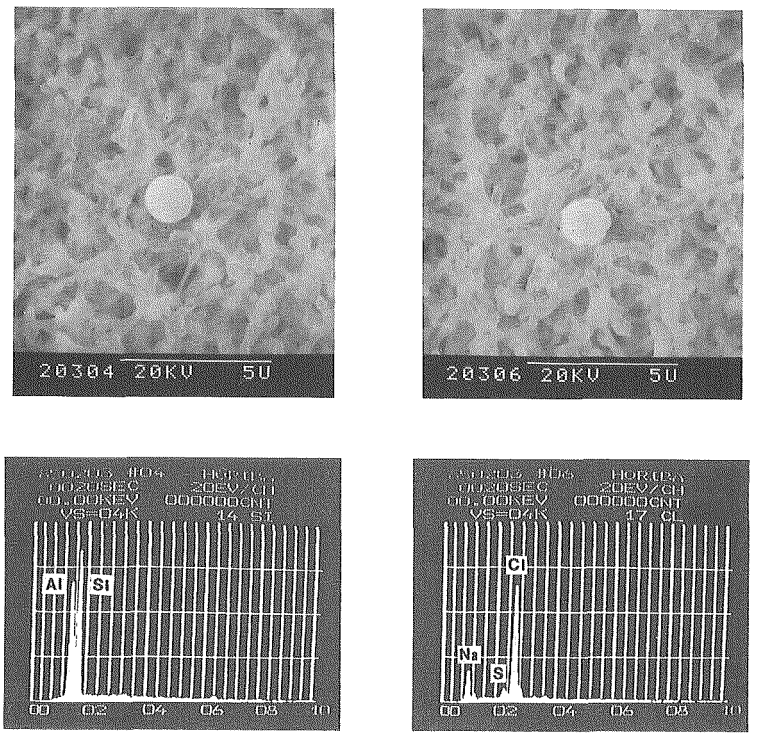


Fig. 9 Chemical components detected from the sample on easterly wind days.

sampling was carried out continuously through day and night during the observation period, no difficulties were encountered. Filter papers on which aerosol particles were collected were sealed tightly and brought back to the author's laboratory. Then the sampled portions on the filter papers were cut out and they were mounted on stages for a scanning electron microscope (HITACHI SEM S-430). The features of individual particles were photographed and then the chemical components were analyzed by an energy dispersive X-ray microanalyzer (HORIBA EMAX-1800E). The EMAX can detect the chemical components included in a particle for elements heavier than sodium. Some results of this analysis will be described below.

At early morning on December 31, 1985, the number concentration of aerosol particles decreased by a change of wind directon from northwest to north. On the north side of the observation site, open snow field spread out.



(a) (b)

Fig. 10 Typical aerosol particles and their chemical components on easterly wind days. (a) : soil particle, (b) : sea salt particle.

From the filter sample at 0500 on December 31, 1985 (the time means a sampling for one hour from this time), fifteen particles were analyzed by SEM-EMAX system. An example of particles is shown in Fig. 8(a). These particles show some crystalline features, and the chemical components included in this particle were Na, Mg, Cl, K and Ca. These particles therefore are considered to have originated from sea salt particles. In Fig. 8(b), the frequencies of detection for each elements are shown in a histogram. It can be seen that the dominant element included in aerosol particles at this time were sea salt elements. However, this histogram expresses only the frequencies of presence or absence for each element. In order to find more detailed information regarding the composition of individual particles, a triangular diagram is also shown at the lower right in this figure. Each point in this diagram indicates the approximate proportion of elements of Si, Na and S, which are selected as the representative elements of soil origin, marine origin and anthropogenic origin, respectively. In this diagram, it is found more clearly that the almost particles were of marine origin.

In order to clarify the origin of air masses which traveled to Inuvik, surface wind data at four observation points around Inuvik, that is, Inuvik, Sachs Harbour, Norman Wells and Yellowknife were used. The wind field indicates that the air mass has originated over the Arctic Ocean. This seems to be unreasonable because the sea surface is covered with sea ice in this region. However, it is possible that there are some open leads which can make dense

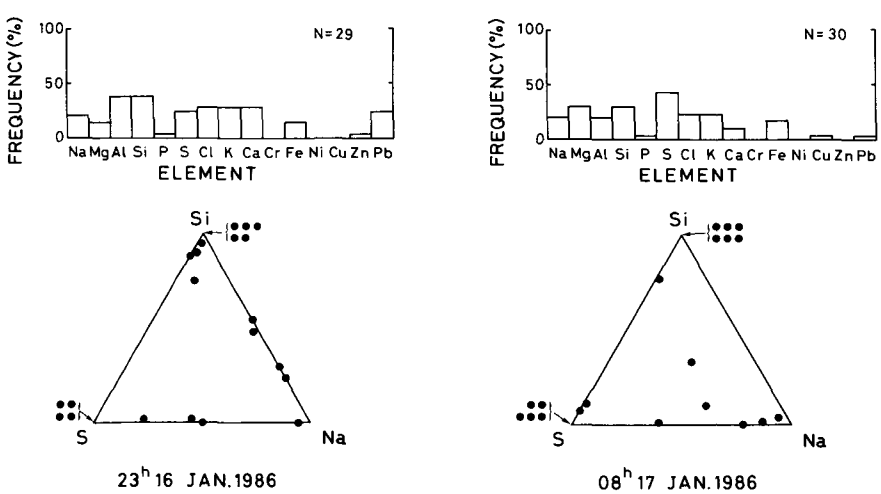
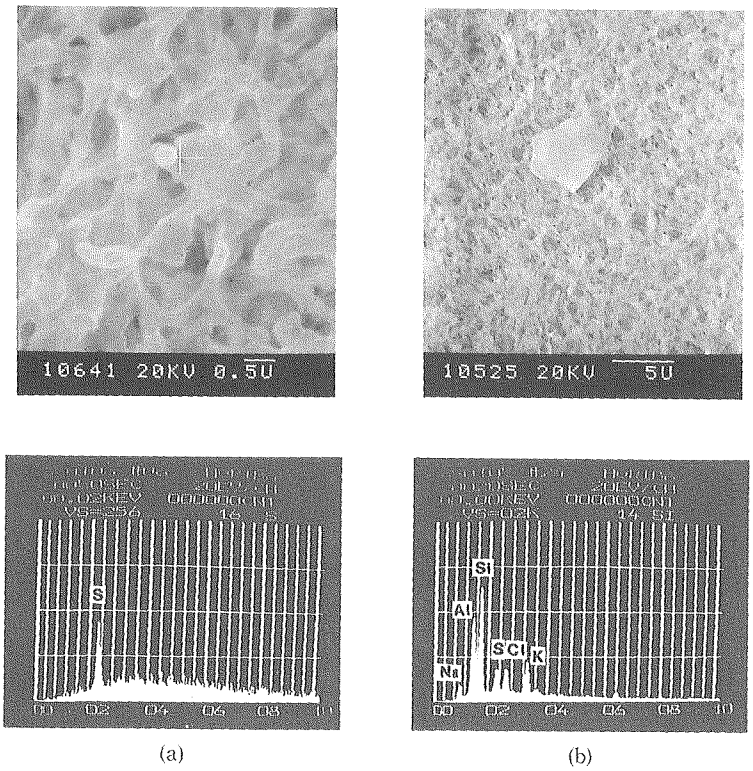


Fig. 11 Same as in Fig. 9, but for diamond dust days.

steam fog caused by the large temperature difference between the sea water and the air. A number of sea salt particles might be supplied to the atmosphere from these open leads.

Other examples are shown in Fig. 9. The samples were collected at 2300 on January 8 and at 2300 on January 5, 1986. In these cases, the wind direction was easterly. The primary chemical component was of marine origin, however, some particles of soil origin were also found secondarily. These can be divided clearly into two groups without any composite particles of both origin. In these cases, the wind field indicates that the air mass came from inland where the soil particles are supplied to the atmosphere. Typical particles of soil origin and marine origin in these cases are shown in Fig. 10.

At 2300 on January 16 and at 0800 on January 17, 1986, the town of Inuvik was covered by diamond dust. The primary chemical component in the aerosol



(a) (b)

Fig. 12 Same as in Fig. 10, but for diamond dust days. (a): sulfur particle, (b): composite particle. Horizontal bar in (a) indicates 0.5 μm.

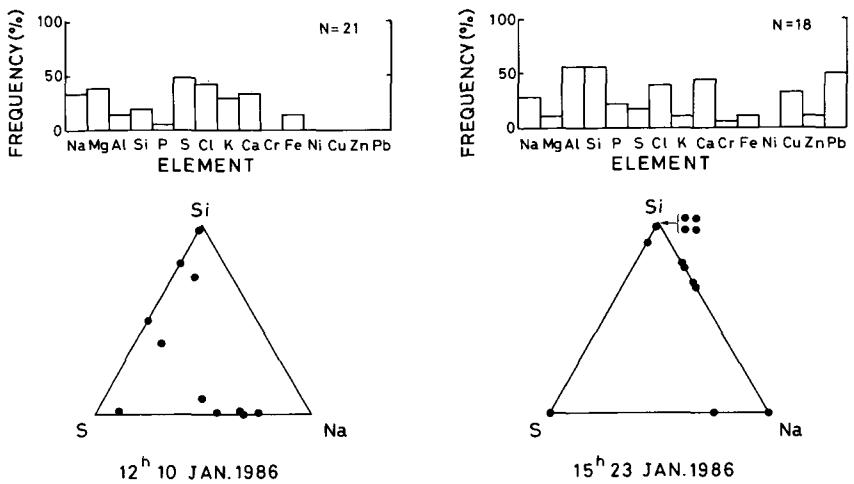
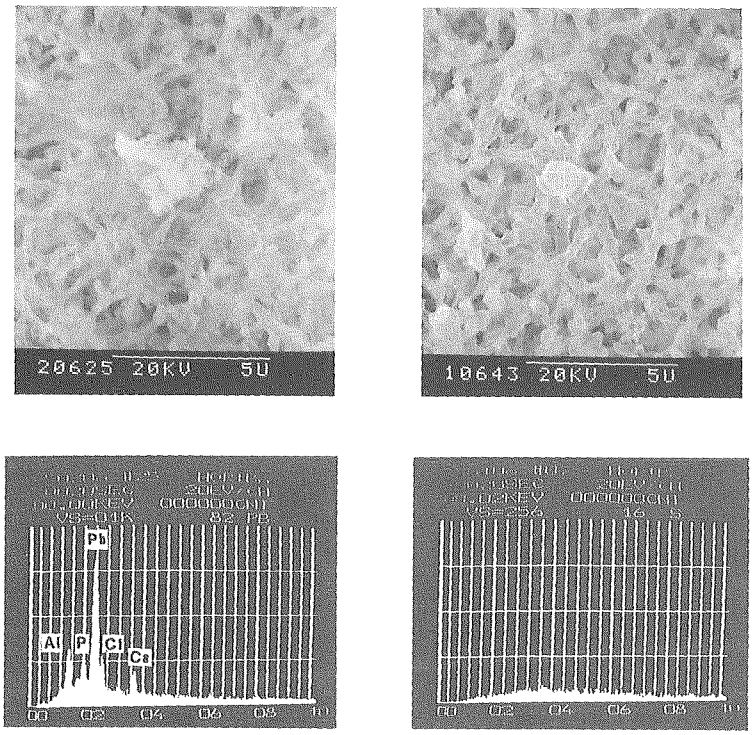


Fig. 13 Same as in Fig. 9, but for polluted days.

particles was of soil origin, and in addition to that, anthropogenic elements such as S and Pb were detected frequently as shown in Fig. 11. Most particles contained sulfur elements to some extent, together with other elements. The abundance of sulfur in the Arctic area is consistent with that reported by Barrie et al. (1981) and Ottar (1981). In the case of particles which consists of only sulfur elements, the size was relatively small as shown in Fig. 12(a). In these cases, the air mass came from the Arctic Ocean, however, the original characteristics of the air mass might be modified considerably by many pollutant particles.

Sulfur and lead were frequently detected also in the case of ice fog days and in the daytime samples on several days as shown in Fig. 13. Lead elements were mainly included in particles which showed a spongy appearance such as the sample shown in Fig. 14(a). These particles may have originated from combustion of antiknocking agents used in gasoline for automobiles. In the midwinter season in the Arctic regions, all automobiles left in parking areas are allowed to idle. On the several days during the observation period, Millipore filter papers were darkened considerably, on which many particles such as shown in Fig. 14(b) were found. Since no chemical elements were detected in these particles, they were presumed to be carbon particles released from the combustion of fuels, because the carbon element could not be detected in this analyzing system.



(a) (b)

Fig. 14 Same as in Fig. 10, but for polluted days. (a) : particles containing considerable lead, (b) : carbon particle.

5. Conclusions

Measurements of the number concentration of aerosol particles in five size ranges were carried out continuously for one month at Inuvik, N.W.T., Canada. The number concentrations of them changed depending mainly upon the wind direction and the stratification of the atmosphere, and in some cases, upon the human activity.

Aerosol particles were collected on filter papers in the same period at Inuvik, and chemical components included in these particles were analyzed by means of SEM-EMAX system. Clear differences were found in chemical components depending upon the meteorological conditions and human activity.

According to the analysis of the wind fields around the observation site, it was found that relatively clean air came in from the Arctic Ocean, containing

numerous sea salt particles. On the other hand, soil particles were carried by air masses which came from the inland part of the North American continent. It is considered therefore that the original characteristics of air masses were modified considerably on calm days, and by human activity.

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