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# Observations of Aerosols Attached to Falling Snow Crystals, Part I, Utilizing an Optical Microscope

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**Abstract**

The size distribution of aerosols attached to falling snow crystals was measured, utilizing optical microscopic photographs of sublimated traces of the snow crystals in Sapporo where the air is highly polluted, in March 1973.

The resolution power of the microscope was insufficient to measure the size distribution of submicron aerosols, and the movement of aerosols towards the center of the snow crystals was recognized. However, within the resolution power, the following results were obtained.

1. In the size distribution of aerosols attached to the snow crystals, the frequency increased smoothly as their size decreased down to 1 $\mu$.
2. Several thousand aerosols were attached to one snow crystal.
3. The area number density of aerosols in a rimed snow crystal of needle type was much greater than in those of plane type. This difference is related to the difference in the thickness of the snow crystals.

## 1. Introduction

It is well known that the air in a city becomes considerably clear after a snowfall. This facts suggests that aerosols in air are washed out (not rained out) by falling snow crystals, because most of aerosols are generally suspended below the cloud base. However no direct measurement has been reported hitherto to prove this washout effect of snow crystals.

On the other hand, several considerations which were presented hitherto, are rather negative for the washout effect. In other words, the collecting efficiency of aerosols of submicron size by falling snow crystals is considered to be negligibly small, owing to the extremely small size of the aerosols, for example we have Langmuir and Blodgett's reports[1]. And the diffusion coefficient of aerosols of this size is also too small to diffuse to the surface of the snow crystals, for example we have Greenfield's report[2]. Nevertheless, the rapid increase in the number of aerosols in air during a snowfall has been frequently observed, as reported by the authors[3,4].

With this in the background, the authors undertook to obtain direct evidence which shows the washout effect of aerosols by falling snow crystals. As a first step, we took microscopic photographs of sublimated traces of snow crystals, although it was forecasted that aerosols attached to a snow crystal would be transported towards the center of the crystal in the sublimation process, as seen in the paper of Nakaya et al[5]. However, it was possible to measure the size distribution of aerosols attached to a snow crystal, utilizing its sublimated trace, if significant coagulation of the aerosols does not occur in the sublimation process, even if the resolution power of the optical microscope is not sufficient. On the other hand, such optical microscopic photographs have a merit to cover a wide area of the snow crystal.

## 2. Observation method

Various methods were tried to minimize the concentration of aerosols towards the center of the snow crystal in the sublimation process. it was eventually found that the usual gradual evaporation at a cold temperature was the best method, and actually the coagulation was not recognized if the sublimation rate was very low.

Falling snow crystals were sampled on a clean glass plate, then one of them was photographed under an optical microscope, as illustrated in Photo. 1 in Pl. I.

After photographing, the glass plate was taken into a shallow capped dish and preserved in a freezer box at temperature of about –20°C. After a few days the sublimated trace of the snow crystal was photographed with magnification factor set at the same size as the previous photograph, as illustrated in photo. 2, Pl. I. Comparing this with Photo. 1, it may be seen that dust particles are distributed roughly on the same area as that where the snow crystal existed before sublimation, although the width of branches was somewhat shrunken. However no significant concentration towards the center is seen.

Several typical portions of the sublimated traces were further photographed with a highest magnification factor, as illustrated in Photo. 3, Pl. I which corresponds to the portion enclosed by a tetragon in Photo. 2, in order to obtain the size distribution of aerosols. Spots enclosed by diffractional rings in the photograph are not related with the aerosols attached to the snow crystal.

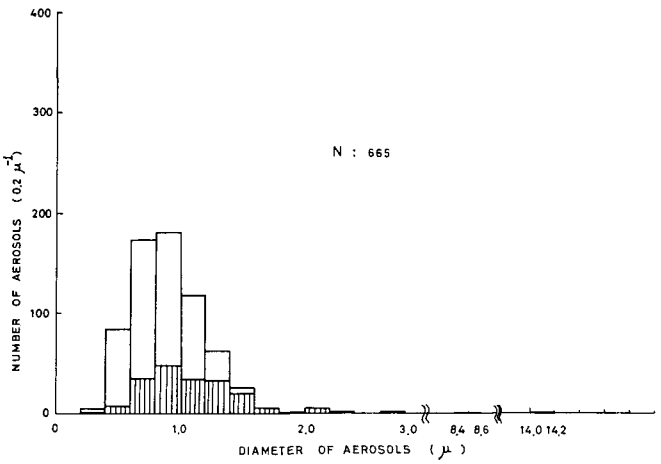


Fig. 1 Size distribution of aerosols attached to a dendritic snow crystal of plane type. (Pl. I)

## 3. Result

Early in the morning on March 10, 1973, a snowfall of snow crystals of dendritic plane type occurred, and the grade of riming was relatively low, as previously shown in Photo. 1, Pl. I. The sublimated trace of the snow crystal is given in Photo. 2.

It may be noted that there are two kinds of spots in Photo. 2, namely black spots and half-transparent spots. The former may consist of smoke particles and the latter may be related to oil droplets from car engine exhaust. The resolution power of the optical microscope is about 1 $\mu$, however the size distribution of aerosols can be described at 0.2 $\mu$ intervals, if we neglect the difference in their shape.

The size distribution counted from a portion enclosed by a tetragon in Photo. 2 is shown in a form of histogram with 0.2 $\mu$ interval in Fig. 1 where shadowed and non-shadowed histograms indicate the distribution of black and half-transparent spots, respectively. $N$ in the figure shows the total number of spots counted. It is noted that the number of aerosols observed, are fairly great in spite of a small portion of the snow crystals, although the snow crystal was sparsely rimed and the number of aerosols smaller than 0.4 $\mu$ is not exact. Considering the area density of aerosols counted, it is estimated that about 4,000 aerosols were attached to the snow crystal.

In any event it may be seen that the maximum of the size distribution was

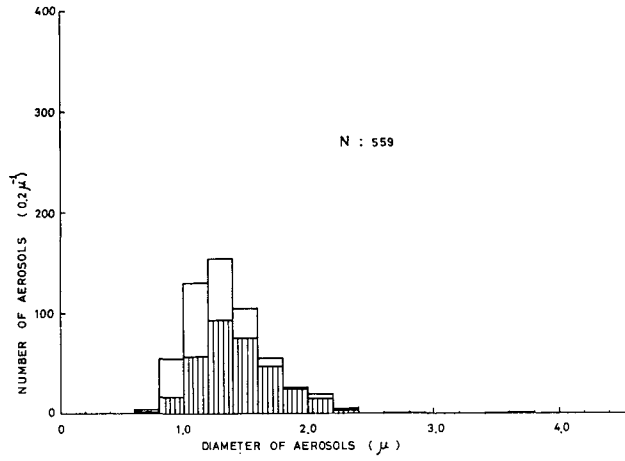


Fig. 2 Size distribution of aerosols attached to a densely rimed snow crystal of plane type. (Pl. II)

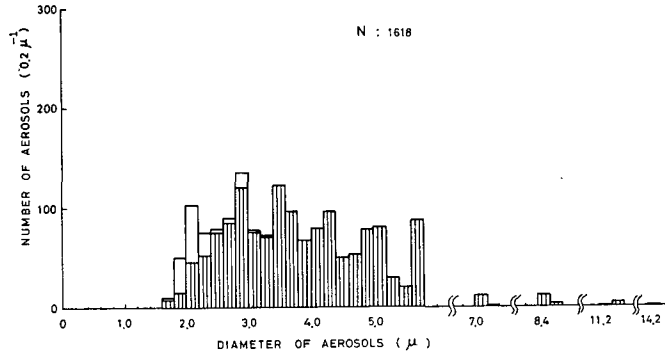


Fig. 3 Size distribution of aerosols attached to a rimed snow crystal. (Pl. III)

about 0.9 $\mu$ diameter, although the size distribution is highly scattered in a range up to 14 $\mu$ in diameter. In the case of large aerosols of micron size, the diameter shown in Fig. 1 means the average of their major and minor diameters. It may be also seen that the size of black spots is distributed in a larger range, compared with half-transparent spots.

Around 03h on March 14, 1973, a snow fall of rimed snow crystals occurred. Four pairs of photographs of snow crystals and the respective sublimation traces were obtained during the snowfall. Photo. 4 in Pl. II shows an example of densely rimed snow crystals of plane type. In this case, small

portions of aerosols were left near the end of branches during the sublimation, however the majority of them seem to be collected in an area near the center of the snow crystal. In spite of the collection at the center, significant coagulation is not recognized, as seen in Photo. 5. The portion enclosed by a tetragon in the photograph is given in Photo. 6, being magnified. The size distribution of aerosols counted from the photograph is shown in Fig. 2. It may be seen that the mode of size distribution is similar to that shown in Fig. 1, although the maximum is somewhat shifted to a larger region.

In case of a snow crystal which is shown in Photo. 7, a short hexagonal column existed at the center of the snow crystal. After the sublimation of the crystal, almost all aerosols were observed at the center of the trace, as seen in Photo. 8, in Pl. III. It is difficult to determine whether the aerosols were concentrated by the shrinkage of the crystal during its sublimation process or whether it originally existed at the center. The size distribution obtained by counting aerosols in Photo. 9 is shown in Fig. 3. It is seen that most of aerosols are black and their sizes are greater than those in Figs. 1 and 2. This suggests a possibility that the coagulation phenomena of aerosols occurred during the sublimation process of the snow crystal. Therefore their size distribution was omitted from further analysis.

In case of a snow crystals shown in Photo. 10, Pl. III, the grade of riming was small, and the concentration of aerosols towards the central portion

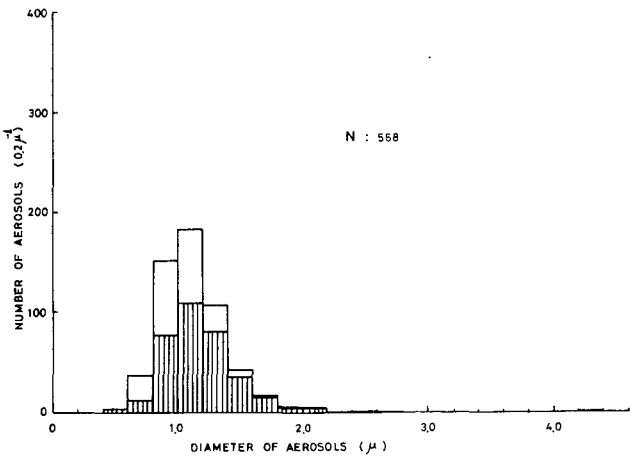


Fig. 4 Size distribution of aerosols attached to a dendritic snow crystal of plane type. (Pl. IV)

during the sublimation process occurred, as seen in Photo. 11, Pl. III, however the analysis of number and distribution were possible, because the grade of concentration was small, as seen in Photo. 12. The size distribution counted from Photo. 12 is shown in Fig. 4. Because two big particles in the photograph seem to be composed of numerous smaller particles, their size distributions were determined by counting the smaller particles included in the big ones, under an assumption that the big particles were formed by collecting the smaller particles in air. It may be seen that the mode of size distribution is similar to those in Figs. 1 and 2.

Around 06h in the morning, the type of falling snow crystals changed from plane type to needle type, and the grade of riming was as great as graupels, as illustrated in Photo. 13 in Pl. V. In this case, the majority of the snow crystals were composed of frozen cloud droplets. The trace of the crystal is shown in Photo. 14, and three portions in the photograph were magnified. One of them enclosed by a tetragon is shown in Photo. 15 from which size distributions of aerosols were determined, as seen in Fig. 5. It may be seen in the figure that there is no significant difference from the previous ones of plane type in Figs. 1, 2 and 4, however it is noted that the number of aerosols counted was considerably greater than in the previous plane snow crystals. This difference may be due to the large grade of riming, more exactly due to the addition of condensation nuclei of frozen cloud droplets.

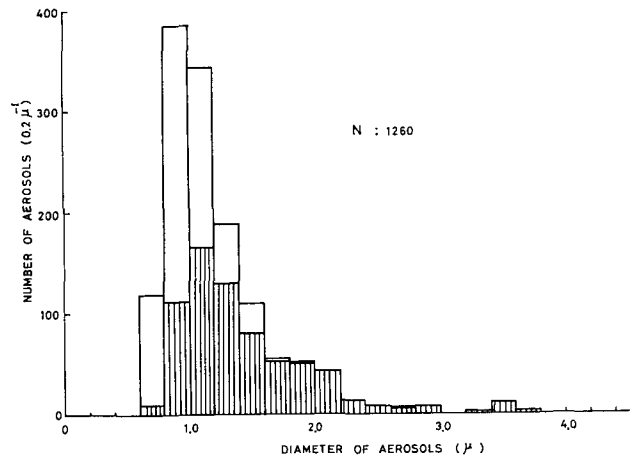


Fig. 5 Size distribution of aerosols attached to a rimed snow crystal of needle type. (Pl. V)

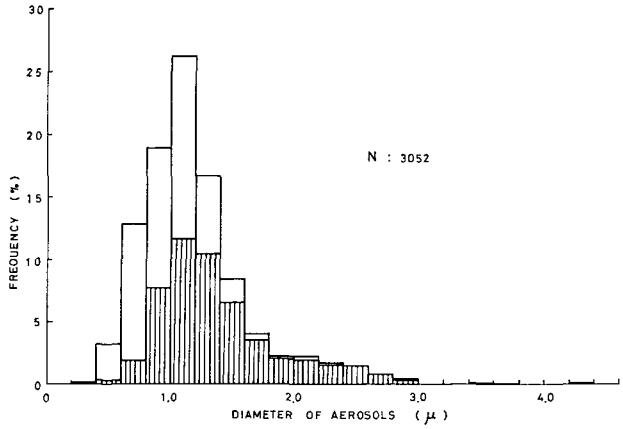


Fig. 6 Size distribution of aerosols counted from all snow crystals except for Pl. III.

Because the modes of size distributions of aerosols attached to snow crystals described hitherto were nearly the same as each other, the average size distribution of them was calculated as shown in percentage in Fig. 6, omitting that in Fig. 3. It may be said that on the whole, the number of aerosols attached to snow crystals increases as their diameters decrease down to 1 $\mu$, as far as detected by the optical microscope.

Under the assumption that the area density of aerosols counted is also uniform in other areas of a snow crystal, the number of attached aerosols greater than 0.2 $\mu$ in diameter was estimated as 2,000 to 4,000 per one snow crystal of several mm in diameter.

## 4. Consideration

Owing to the resolution power of optical microscope used, the measurement of aerosols was not accurate in a range smaller than 1 $\mu$, and the movement of attached aerosols was not completely avoided in the sampling process. Within these limits, the following considerations were made.

The number of aerosols attached to the snow crystal smoothly increased, as their size decreased down to 1 $\mu$. It appears that the number decreased again in the range smaller than 1 $\mu$, however this decrease is only an apparent one, because aerosols smaller than the resolution power are likely to be missed in counting.

There was no significant difference in the modes of size distributions of attached aerosols according to the difference in crystal type or to the difference

in the grade of riming. The modes of size distribution were also similar to that in previous observations[4]. This may be a reflection of the size distribution of aerosols in air under the cloud base over a city.

The apparent area density of aerosols attached to a rimed snow crystal of needle type was considerably greater than those of a plane type. This may be because the thickness of the rimed snow crystal was much greater than those of plane type.

The number of aerosols attached to snow crystals was estimated as 2,000 to 4,000 per one snow crystal. This value is roughly in agreement with the previous observation by the authors[4].

Kuroiwa[6] observed condensation nuclei of fog particles by use of an electron microscope. According to the results of his observation, the size of condensation nuclei ranged from 0.2 to 1 $\mu$ in diameter. This range is overlapped over a smaller range of the present distributions of aerosols. Therefore, if snow crystals are rimed, it is probable that condensation nuclei of rimed cloud droplets are included in the present distributions. However there was no significant difference in the modes of size distributions of rimed snow crystals and non-rimed snow crystals as far as the plane type snow crystals were concerned. This may be because aerosols in a range smaller than 0.4 $\mu$ were mostly missed in counting.

## 5. Conclusion

Aerosols attached to falling snow crystals were observed, utilizing an optical microscope, and the following results were obtained.

1. The number of attached aerosols smoothly increases, as their size decreases down to 1 $\mu$.
2. There was no significant difference due to the type of snow crystals or the grade of riming.
3. 2,000 to 4,000 aerosols greater than 0.2 $\mu$ in diameter were attached to one snow crystal.

Owing to the limit in resolution power of the microscope, the measurement of aerosols smaller than 1 $\mu$ was not exact. The result of measurements of an electron-microscope will be presented in the next paper.

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Pl. I Aerosols attached to a dendritic snow crystal of plane type.

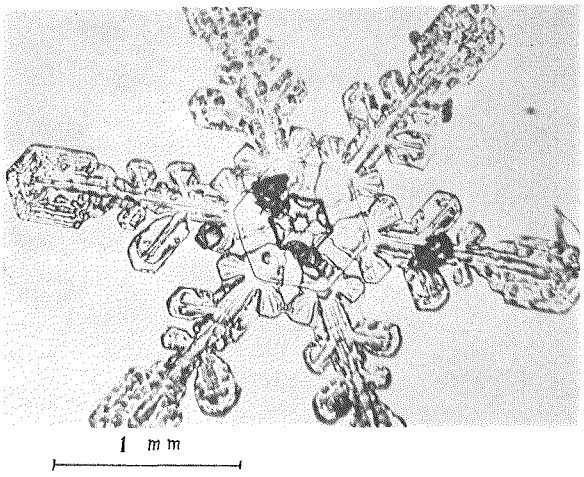


Photo. 1 Dendritic snow crystal of plane type.

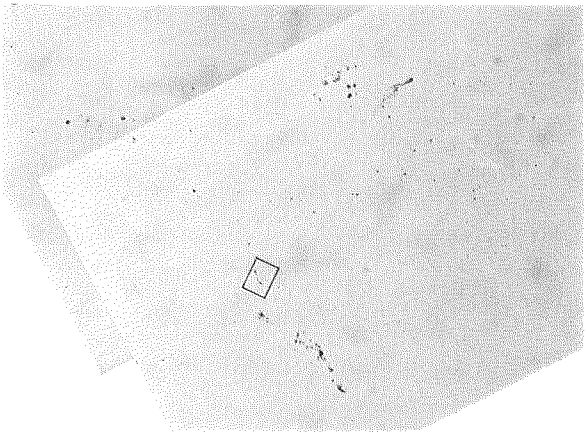

Photo. 2 Sublimated trace of the snow crystal above.

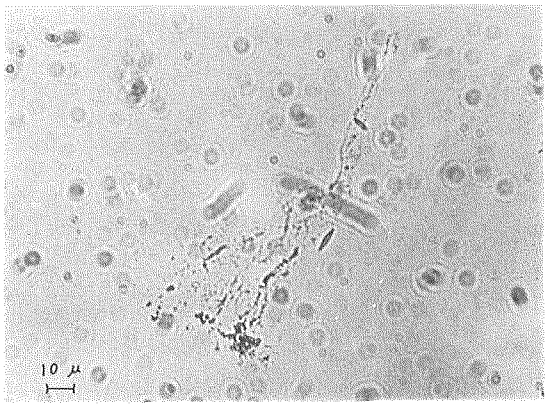


Photo. 3 Aerosols in area enclosed by a tetragon in Photo. 2.

Pl. II Aerosols attached to a densely rimed snow crystal of plane type.

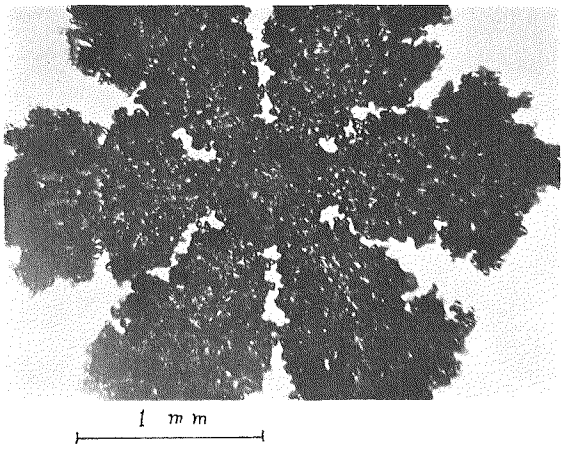


Photo. 4 Densely rimed snow crystal of plane type.

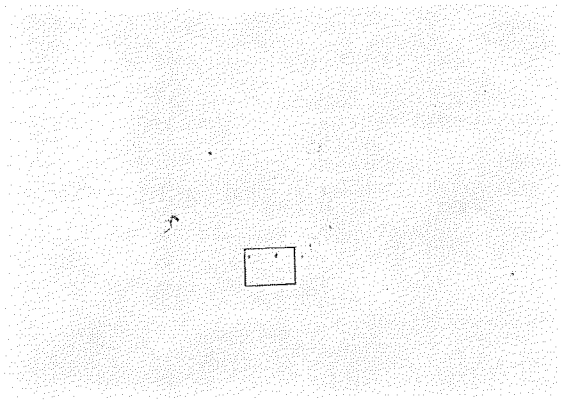

Photo. 5 Sublimated trace of the snow crystal above.

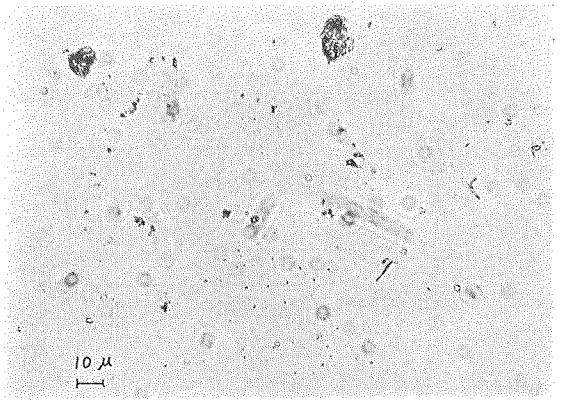


Photo. 6 Aerosols in area enclosed by a tetragon in Photo. 5.

Pl. III Aerosols attached to a rimed snow crystal.

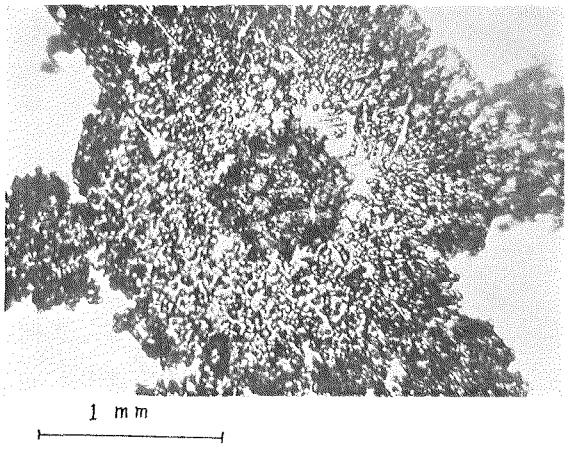


Photo. 7 Rimed snow crystal of plane type.

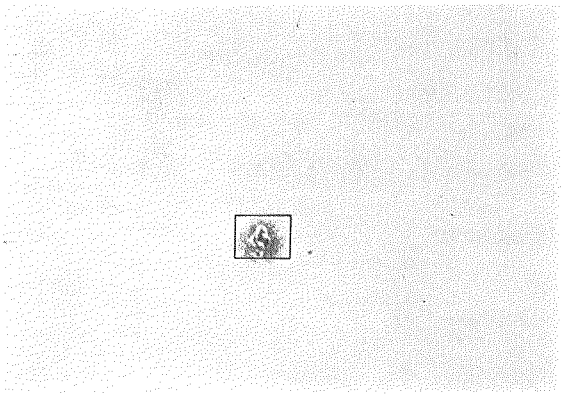

Photo. 8 Sublimated trace of the snow crystal above.

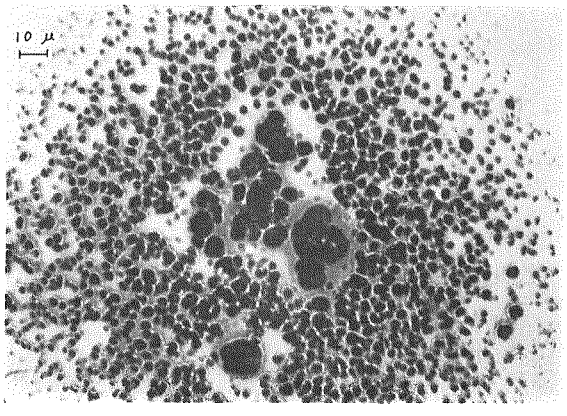


Photo. 9 Aerosols in area enclosed by a tetragon in Photo. 8.

Pl. IV Aerosols attached to a dendritic snow crystal of plane type.

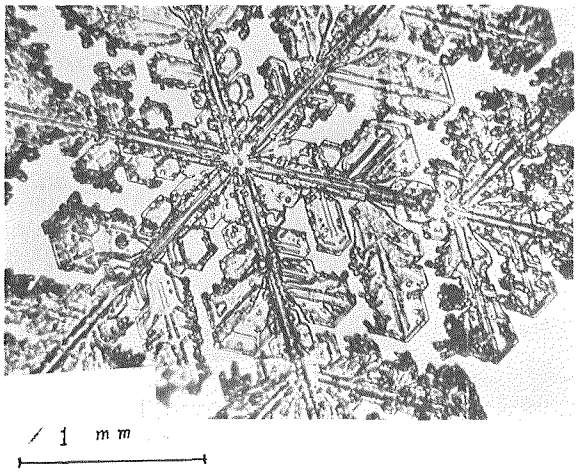


Photo. 10 Dendritic snow crystal of plane type.

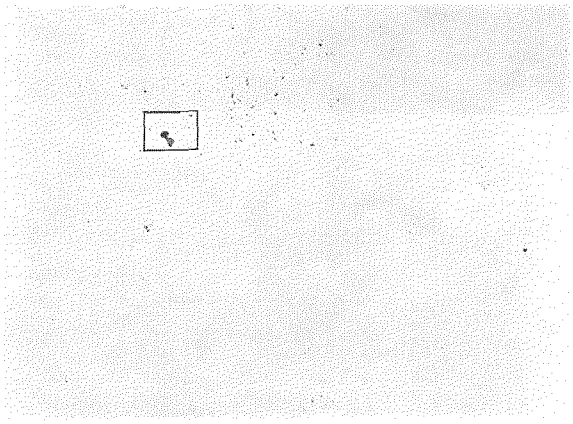

Photo. 11 Sublimated trace of snow crystal above.

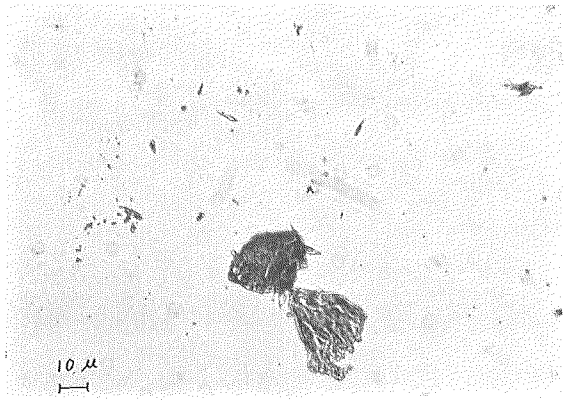


Photo. 12 Aerosols in area enclosed by a tetragon in Photo. 11.

Pl. V Aerosols attached to a rimed snow crystal of needle type.

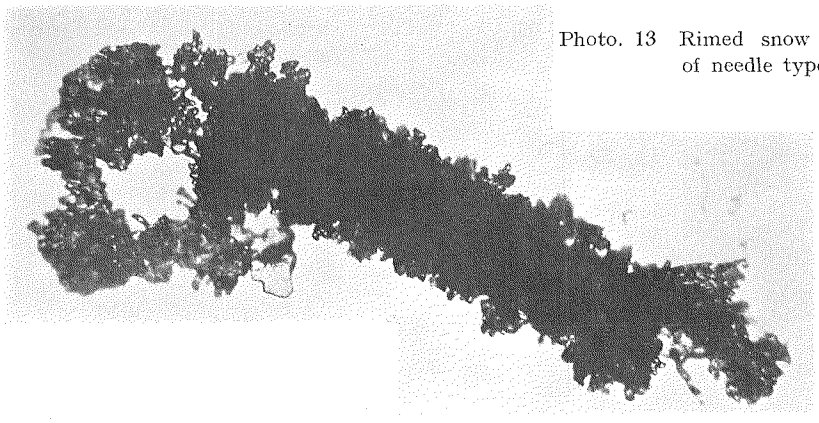

Photo. 13 Rimed snow crystal of needle type.

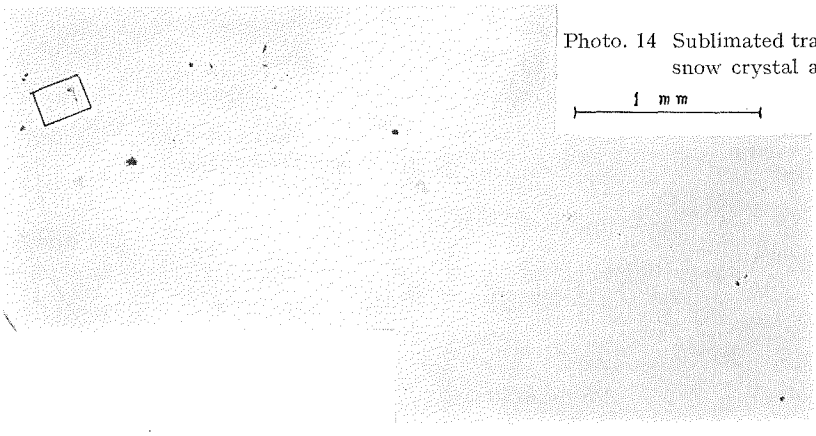


Photo. 14 Sublimated trace of the snow crystal above.

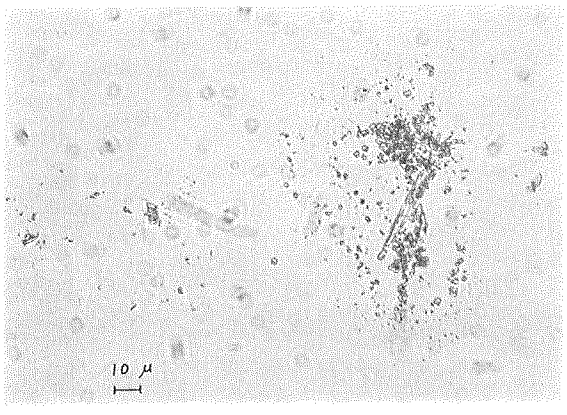


Photo. 15 Aerosols in area enclosed by a tetragon in Photo. 14.