THE EFFECT OF THE ICE NUCLEUS ON THE SHAPE OF SNOW CRYSTALS

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Abstract: Ice crystals were produced in a supercooled cloud by seeding rock-forming minerals and clay minerals in a large cloud chamber of about 6.5 m in height, and the effect of ice nuclei on the shape of ice crystals was examined. (i) The frequency of ice crystals of polycrystalline type is high when seeded at temperatures about $-25°C$. Among them the frequency of assemblages of plates is especially high and so-called "peculiar shaped crystals" are less than 10%. (ii) The frequency of ice crystals of polycrystalline type increases with the increase of the size of ice nuclei. (iii) Ice crystals grown from the nuclei of polycrystalline type are polycrystalline in the case when the size of the nuclei is larger than 10 μm.

1. Introduction

It was pointed out by NAKAYA (1954), HALLETT and MASON (1958) and KOBAYASHI (1957, 1961) that the habit of snow crystals depended mainly on temperature and supersaturation. These studies were conducted mainly for snow crystals of single-crystalline type which showed hexagonal symmetry, and little attention was paid to snow crystals of polycrystalline type although polycrystalline snow crystals have been observed frequently since the observation of NAKAYA. Recently KIKUCHI (1970) observed snow crystals of various shapes in Antarctica which had not been reported, and he termed them "peculiar shaped crystals"; YAMASHITA (1971) succeeded in making various ice crystals of polycrystalline type including V-shaped crystals by seeding dry ice or a metal rod chilled by liquid nitrogen. Their studies stimulated attention to the structure and origin of snow crystals of polycrystalline type. Polycrystalline ice nuclei are considered to be the origin through deposition nucleation. In this case the crystallinity and the shape of snow crystals are affected by the properties of ice nuclei. SCHAEFER and CHENG (1968) indicated first the effect of ice nuclei on the shape of snow crystals, although polycrystalline snow crystals were not included. YAMASHITA (1974) has also confirmed the importance of the nucleation process for the growth of ice crystals by seeding with various methods. The present experiment was carried out to examine the effect of ice nuclei, their size and their crystallinity on the shape of ice crystals, and to investigate the possibility of polycrystalline ice nuclei as an origin of snow crystals of polycrystalline type.

2. Experimental Apparatus and Procedures

The experimental apparatus is shown in Fig. 1. It is the same type of the cloud

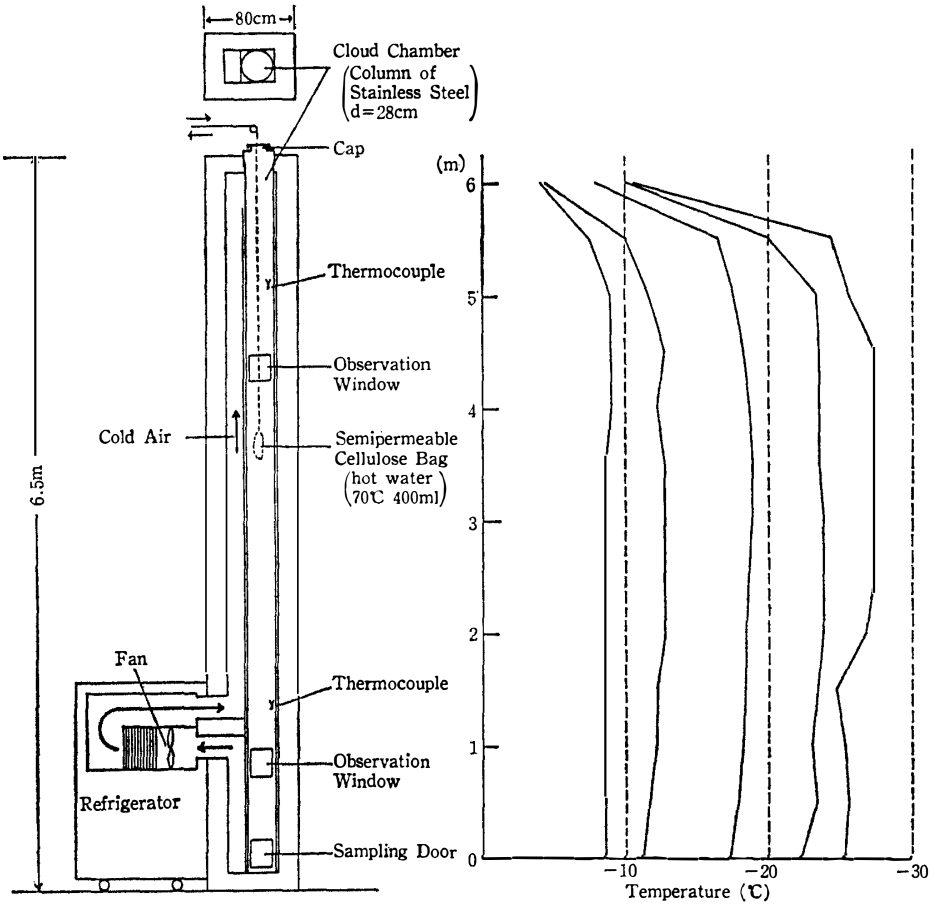

Fig. 1. Large cloud chamber and vertical temperature profiles in the chamber.

chamber used by YAMASHITA (1971). It is made of a column of stainless steel (about 6.5 m in height and 28 cm in diameter). The chamber is cooled by circulating cold air around it. Vertical profiles of the temperature in the chamber are shown in Fig. 1. The temperature is kept uniform within ± 1.5°C from 1 m below the top to the bottom and can be reduced to -33°C. Temperatures in the chamber are measured continually during the experiments at two points; 1.5 and 5.2 m below the top. Supercooled cloud is produced by hot water (about 400 m*l* and 70°C) in a semipermeable cellulose bag. The bag is suspended with a string, introduced from the top, hung down to the bottom and removed from the top of the chamber. Ice nuclei are seeded after the temperature in the chamber gets stable. Ice crystals grow in a supercooled cloud and fall to the bottom of the chamber. They are collected in a silicone oil and are covered with coverglass to prevent evaporation.

Five samples of rock-forming minerals and two clay minerals were tested. They were quartz, gypsum, orthoclase, augite, kaolinite from Mitsuishi of Okayama Prefecture and montmorillonite from Yokokawa of Gunma Prefecture. Fine particles of rock-forming minerals were prepared by crushing the minerals in an iron mortar and grinding them finely in an agate mortar. The particles were dispersed as powder into a supercooled cloud formed in the chamber.

3. Results

3.1. Effect of ice nuclei

Ice nuclei were tested at temperatures about $-25°C$. Collected ice crystals were classified into single-crystalline type and polycrystalline type, and the latter was classified again into assemblages of plates, assemblages of plates and columns, and other polycrystals. Typical ice crystals of each type are shown in Fig. 2 and their frequencies are shown in Fig. 3. Polycrystalline ice crystals grew frequently in every case and their frequencies exceeded 80% when seeded with clay minerals. The frequency of assemblages of plates was especially high and that of other polycrystals was less than 10%. This result agreed well with the observation of natural snow crystals by KAJIKAWA *et al.* (1980).

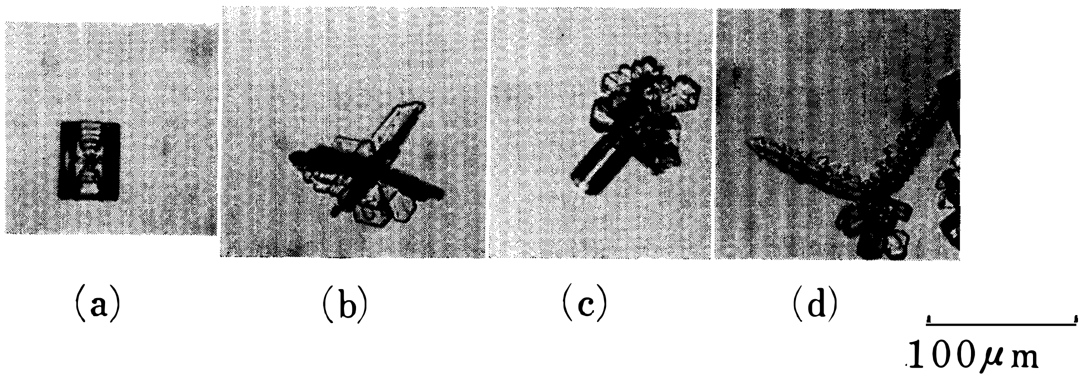

Fig. 2. Ice crystals grown at temperatures about $-25°C$. (a) Column, quartz, (b) Assemblage of plates, quartz, (c) Assemblage of plates and columns, orthoclase, (d) Peculiar shape, orthoclase.

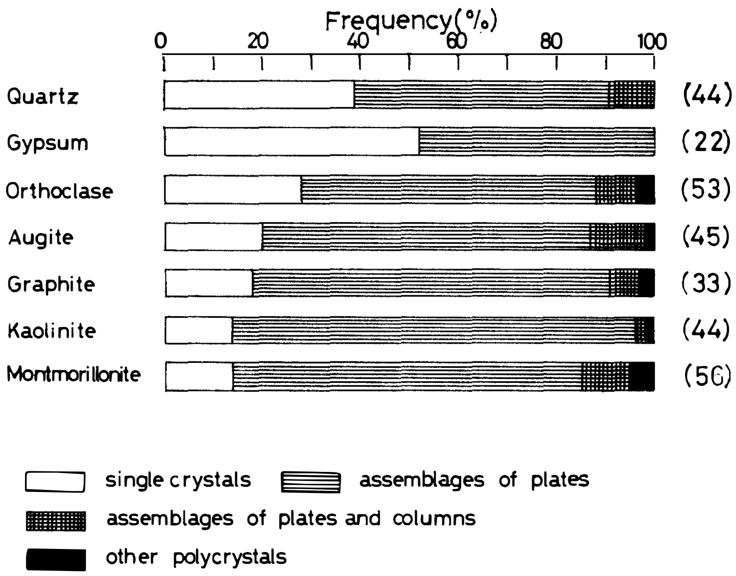

Fig. 3. Frequency of ice crystals of each type when seeded with seven kinds of ice nuclei. Numerals in parentheses show the number of observed crystals.

3.2. Effect of the size and the crystallinity of ice nuclei

In order to investigate the effect of the size and the crystallinity (either single-crystalline or polycrystalline) of the nuclei, ice crystals were evaporated and the particles left at the center were observed by a polarizing microscope. Experiments were made at temperatures about $-15°C$ by seeding with orthoclase. The relation between the crystallinity of ice crystals and the size of their nuclei is shown in Fig. 4. The observed nuclei were classified into three groups according to their size. The larger the size of the nuclei the frequency of growing into polycrystalline ice crystal was high. This tendency is explained by considering that large nuclei have many nucleating sites or are composed of more than two crystals and each nucleating site or crystal grows to one component of polycrystalline ice crystals.

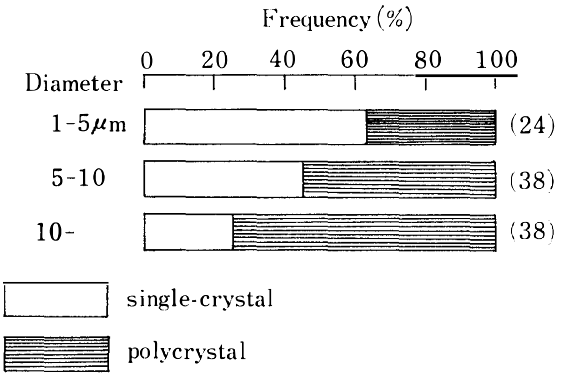

Fig. 4. Frequency of ice crystals of single-crystalline and polycrystalline types. Ice crystals were produced by seeding orthoclase at temperatures about $-15°C$.

Table 1. Relation between the crystallinity of ice crystals and that of their nuclei.

	Single-crystalline ice nuclei	Polycrystalline ice nuclei	Total
Single-crystalline ice crystals	8	0	8
Polycrystalline ice crystals	5	25	30
Total	13	25	38

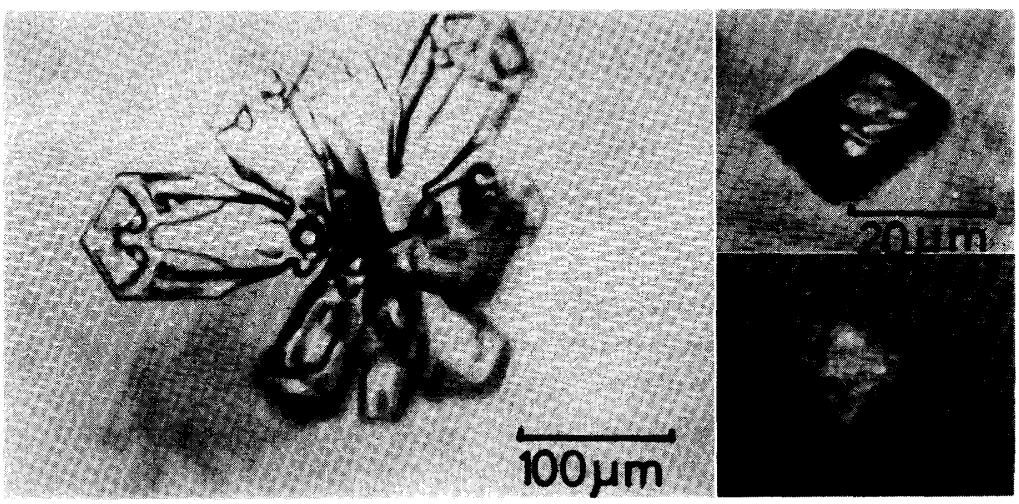

Fig. 5. An ice crystal of polycrystalline type and its nucleus (in transmitted light and in transmitted polarized light).

The crystallinity of nuclei was determined only for those of size larger than 10 μm. The result is shown in Table 1. Among 38 nuclei 25 were polycrystalline and all the ice crystals grown on them were polycrystalline. An example is shown in Fig. 5. Among 13 nuclei of single-crystalline type 8 produced single-crystalline ice crystals and other 5 nuclei produced polycrystalline ice crystals.

4. Discussion and Conclusions

As the origin of snow crystals of polycrystalline type two cases are mentioned: one is polycrystalline nuclei and the other is polycrystalline frozen droplets. KOBAYASHI *et al.* (1976) proposed the latter possibility. Their opinion was supported by the measurement of the crystal axis of frozen droplets made by UYEDA and KIKUCHI (1978, 1980). However, there still remains the problem how water droplets freeze into polycrystalline particles. The most probable mechanism of freezing of water droplets in natural clouds is the nucleation by contact with ice nuclei. Although this nucleation mechanism was considered to be highly effective in early experiments or field observations, recent experimental works indicate that contact nucleation contributes at most only 2–5% (KATZ and PILLÉ, 1974; KATZ and MACK, 1980). The effectiveness of contact nucleation in natural clouds is in question. If contact nucleation occurs frequently, the probability that water droplets of cloud droplet size (about 10 μm in diameter) freeze into polycrystalline particles at temperatures above -30°C is expected to be small according to the experimental result of PITTER and PRUPPACHER (1973). Moreover, the present author observed that polycrystalline frozen droplets accreted to columns grew into assemblages of thin plates even at temperatures about -25°C (TAKAHASHI, 1979). This observational result contradicts the opinion that a combination of bullets originates from frozen droplets. Thus polycrystalline snow crystals do not always originate from frozen droplets and the possibility that they grow from polycrystalline nuclei through deposition nucleation cannot be neglected, especially for a combination of bullets and "peculiar shaped crystals". The correspondence between the crystallinity of ice nuclei and that of snow crystals shown in the present experiment indicates that ice unclei act as deposition nuclei and supports the possibility, although several polycrystalline ice crystals have single-crystalline particles at their center. The reason for this result is not known except the possibility that those nuclei had a very small part with different crystal axis from the main part and was not distinguished as polycrystalline particles. The present experiment is restricted by the use of an optical microscope, and the use of electron diffraction method expected to bring about a good result on the determination of crystallinity of small particles which act as ice nuclei in the atmosphere.

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