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Morphological Studies on the Polycrystalline Snow Germs

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Abstract

From among a number of microphotographs of ice and snow crystals photographed in the ice needle and ice fog phenomena observed in the Arctic and Antarctic regions, polycrystalline initial ice crystals (poly-snow germs) were selected and classified into twelve types. Almost all of them were crossed plates type and their formation rate was approximately 5%. To investigate the shapes of artificial poly-snow germs and their production rate, laboratory experiments using a cloud chamber were carried out under the temperature conditions between -18 and -42°C . As a result, almost all shapes that were observed in nature were produced in the chamber and the production rate was less than 5%. This value was similar to that of observational results. As one of mechanisms of the growth of these poly-snow germs, the cubic structure model which was introduced into the snow polycrystals by Furukawa (1982) might be possible.

1. Introduction

Since the pioneering work by Nakaya (1954), a number of studies of the structure, growth processes and growth mechanisms of single and polycrystalline snow crystals have been done to date (Kobayashi, 1961; Magono and Lee, 1966; Kobayashi et al., 1976; Furukawa, 1982; Gonda and Koike, 1982). Recently, the growth mechanisms of polycrystalline snow crystals of low temperature types which have more complicated shapes have attracted our attention (Kikuchi and Sato, 1984; Kikuchi, 1987, 1989; Uyeda and Kikuchi, 1990; Kikuchi et al., 1991).

On the other hand, reports concerning the polycrystalline initial ice crystals (hereinafter, poly-snow germs) which are smaller than $100\text{ }\mu\text{m}$ in maximal dimension have not been published to date, except for some sketches by Klinov (1960). Therefore, the microphotographs of poly-snow germs taken at the Arctic and Antarctic regions by one of the authors (K.K.) were examined from

a view point of their shapes and formation rate in nature. To investigate the shapes of artificial poly-snow germs and their production rate, laboratory experiments using a cloud chamber were carried out under the temperature conditions between -18 and -42°C . It is important for the understanding of the growth mechanisms of snow crystals of low temperature types that have attracted our attention. In this paper, therefore, both observational and experimental results will be described.

2. Examinations of poly-snow germs

2.1 *Microphotographs used for the analysis*

The main objective of snow and ice crystal observations at the Arctic and Antarctic regions was to understand the growth mechanisms of snow crystals of low temperature types termed gohei twin, seagull and spearhead types (ex. Kikuchi, 1987, 1989). At first, therefore, our attention was not focused on the poly-snow germs. Since the observations of clear sky precipitation were carried out at the South Pole Station, Antarctica and a number of initial hexagonal plates with solid columns and long prisms as shown in Fig. 1 were observed under the surface air temperature conditions between -35 and -37°C , our attention was focused on the initial hexagonal and non-hexagonal plates (Kikuchi and Hogan, 1979). Because, it had been known by the T - $\Delta\rho$ diagram for snow crystal habit and growth mode that the shapes of sheaths, hollow prisms and solid columns alone without plates were possible to grow below -22°C . Figure 2 represents a time sequence of number concentrations of single initial ice crystals observed at the South Pole Station, Antarctica transcribed from Kikuchi and Hogan (1979). In this figure, the open, solid and striped histograms denote the number concentrations of column (Fig. 1(a) and (b)), hexagonal plate (Fig. 1(c)) and other plates, including scalene hexagonal, triangular and so on (Fig. 1(d) to (l)), respectively. Under the air temperature conditions between -35 and -37°C , it is worthy of attention that more than half of the number concentration was occupied frequently by the plate type crystals. However, we did not find the shapes of poly-snow germs at this time. Then, we focused our attention on the classification of the microphotographs of poly-snow germs obtained by the polarization microscope studies carried out ranging over seven times at four observation sites; i.e., at the South Pole Station (90°S), Antarctica in the austral summer of 1975/76 and 1978/79, at Inuvik ($68^{\circ}22'\text{N}$, $133^{\circ}42'\text{W}$), Arctic Canada in the winter of 1977, 1979/80 and 1985/86, at Kautokeino ($69^{\circ}01'\text{N}$, $23^{\circ}03'\text{E}$), Northern Norway in the winter of 1987/88 and at

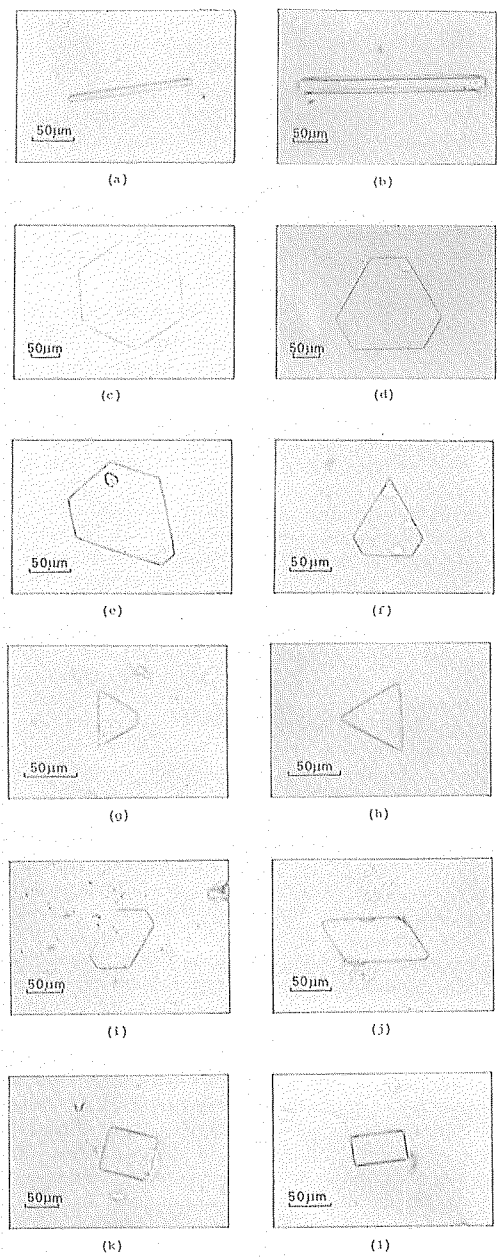


Fig. 1. Examples of microphotographs of single initial ice crystals replicated at the South Pole Station, Antarctica (after Kikuchi and Hogan, 1979).

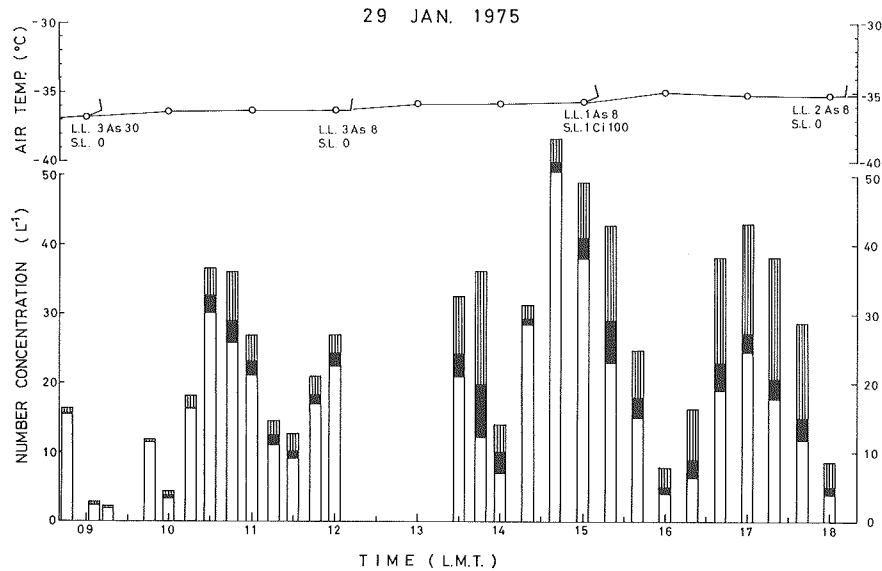


Fig. 2. Time sequence of the number concentrations of single initial ice crystals observed at the South Pole Station, Antarctica (after Kikuchi and Hogan, 1979).

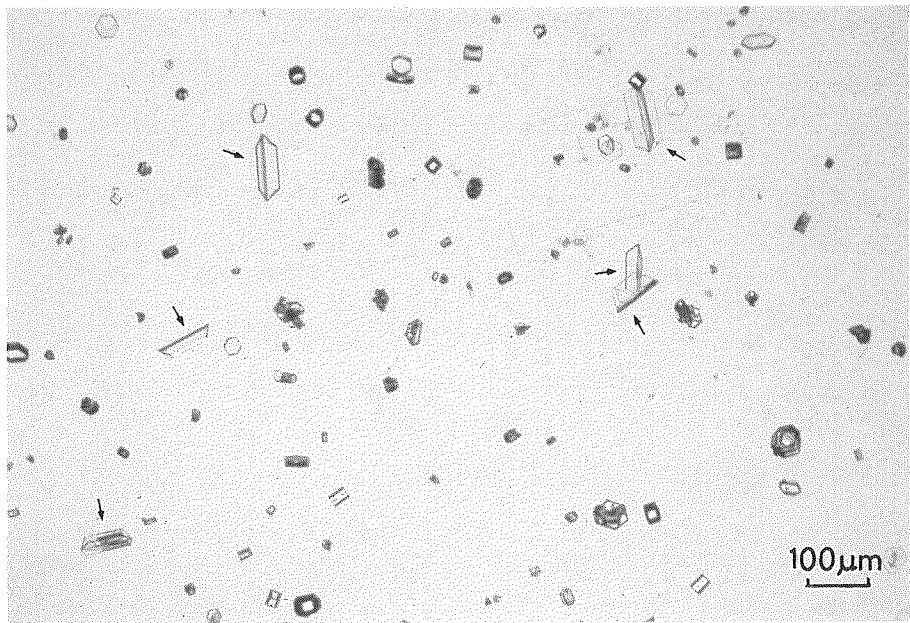


Fig. 3. Microphotograph of ice fog particles taken at Inuvik, Arctic Canada. Arrows indicate poly-snow germs.

Godhavn (69°15'N, 53°34'W), West Greenland in the winter of 1989/90.

2.2 Classification of poly-snow germs

Examples of the microphotographs of poly-snow germs were selected from among a number of microphotographs of ice and snow crystals photographed at the above described four observation sites. Figure 3 represents one of microphotographs taken by a low magnification of ice fog particles at Inuvik. It is seen easily that there are some poly-snow germs pointed out from arrows among minute columns and plates. Figure 4 represents some examples of the high magnification of poly-snow germs. Figure 4(a) is one of the typical and simplest types observed at Inuvik. In this example, the poly-snow germ consists of an elementary hexagonal plate and a supplementary half plate and they should form an angle between the elementary and supplementary plates of 70.5° and 109.5° for the supplementary angle from the cubic structure model

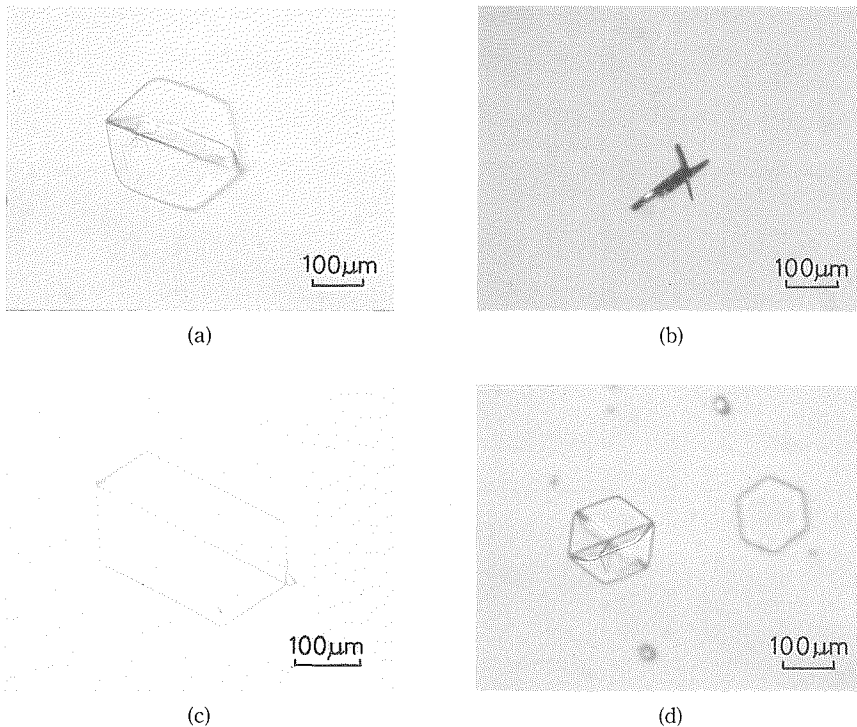


Fig. 4. Microphotographs of poly-snow germs. (a) Inuvik, Arctic Canada, (b) Godhavn, Greenland, (c) Inuvik, Arctic Canada, (d) South Pole Station, Antarctica.

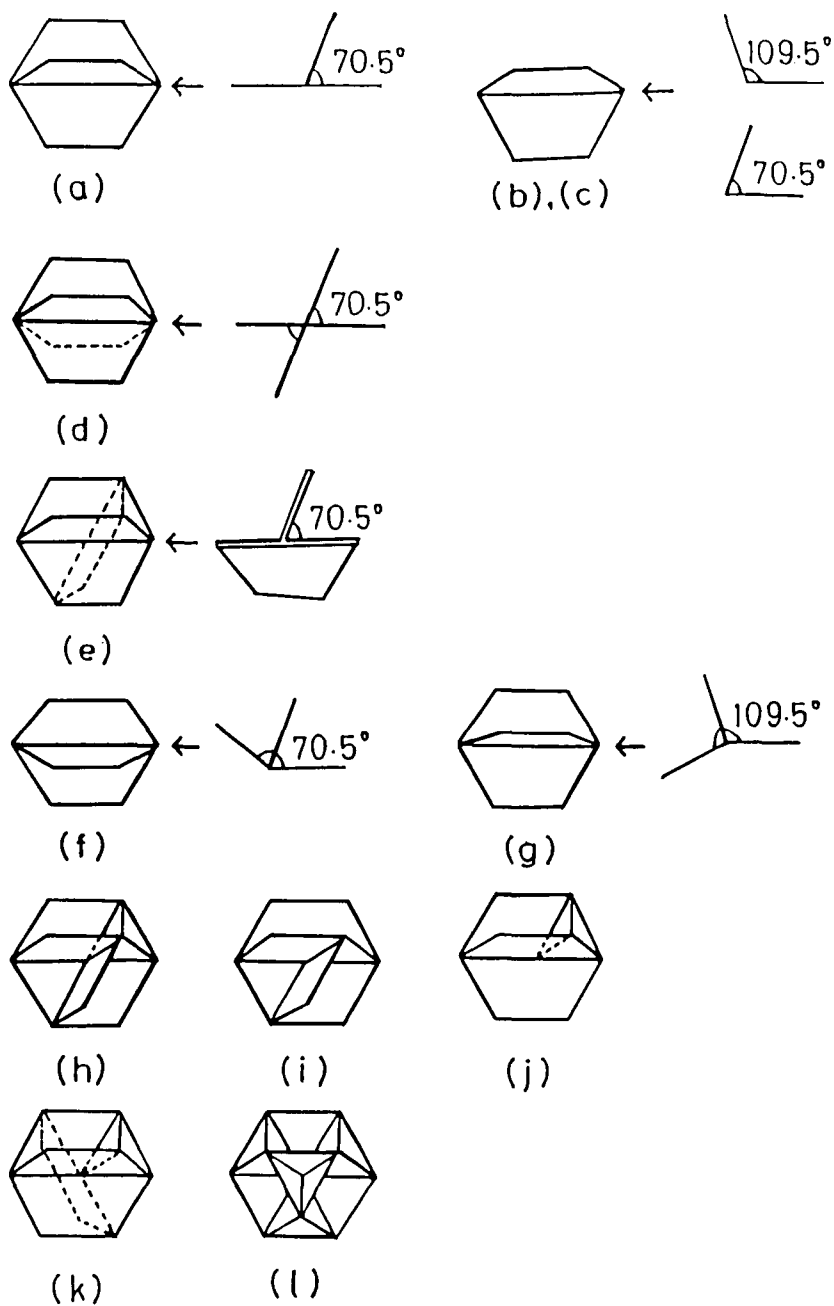












Fig. 5. Classification of poly-snow germs.

introduced by Furukawa (1982). Figure 4(b) represents another example of poly-snow germs directing to the common a -axis to this side to understand the angle between both plates observed at Godhavn. The crystal does not point exactly on this side at right angles, however, it could be estimated easily that the angle is similar to that described above. Although the Fig. 4(c) seems to form a similar type as the former ones, they are different from each other because the type Fig. 4(c) does not have plates. Figure 4(d) represents an example of more complicated one sampled at the surface air temperature of -45°C in South Pole. Two plates and one plate are recognized on the upper and lower faces respectively of the elementary hexagonal plate in this crystal. Based on our observations, we classified poly-snow germs into (a) to (l) type as shown in Fig. 5.

Table 1. Summary of the poly-snow germs observed at the polar regions (G: Godhavn in West Greenland, I: Inuvik in Arctic Canada, S.P.: South Pole Station in Antarctica).

	Type	G	I	S.P.	Total
	a	5	24	2	31
	b, c	6	26	4	36
	d	3	2	1	6
	e	0	1	0	1
	f, g	1	7	0	8
	h	0	4	2	6
	i	3	5	3	11
	j	0	3	1	4
	k	0	2	0	2
	l	0	1	1	2
	Other shapes	4	11	6	21
	Total	22	86	20	128

Types (a) to (c) in Fig. 5 are the most typical and simplest ones, and the type (a) corresponds to Fig. 4 (a), and types (b) and (c) to Fig. 3, respectively. Three types of crystals are the most popular and prevailing in the low temperature conditions lower than -20°C during ice fog and ice needle phenomena as shown in Fig. 3. The type (d) is also a typical one corresponding to the Fig. 4(b) and crossed plates in the meteorological classification of snow crystals by Magono and Lee (1966), and referred to as the scalelike side planes in the general classification by Nakaya (1954). The type (e) is different from (d) with two common a -axes. The types (f) and (g) do not have an elementary hexagonal plate and the (g) is similar to that in Fig. 4(c). The types (h) to (j) have similar characteristics in which two plates are on the same side, on this side in these sketches. However, the plate has frequently incomplete growth as seen in the types (i) and (j). The type (k) is characterized by the type (e) basically and by an incomplete plate such as the type (j). This type corresponds to Fig. 4(d). Putting together these types, it is considered that these plates can grow on one side of the elementary hexagonal plate as shown in the type (l). As these plates, therefore, have a possibility both sides of the elementary plate, they seem to be the most complicated externally. In any case, it can be concluded that all poly-snow germs consist of a combination of the types (a) to (l).

Table 1 summarizes the results observed at Godhavn (G), Inuvik (I) and the South Pole (S.P.), respectively. The types of (a) to (d) indicate 60% approximately on the average.

3. Experiments of artificial poly-snow germs

3.1 *Experimental setup*

A schematic diagram of the cloud chamber used is shown in Fig. 6. The chamber of 12 cm in diameter and 35 cm in height is the same one used by Magono et al. (1979) except for a coolant tube. The chamber was set up in a cold room of -15°C and the experiments were carried out under the temperature condition inside of the chamber between -18 and -42°C with running chilled coolant and dry ice. Water vapor was supplied from a heated water reservoir from an upper part through a wet gauze filter. Before the experiments, the water vapor was supplied for long period and dust free conditions were maintained inside the chamber. When the supercooled water droplets were examined, the droplets formed by a supersonic humidifier were inserted inside the chamber. The size distributions of the supercooled water droplets used were 2 to 20 μm with the maximal peak of 6 μm in diameter. Dispersion

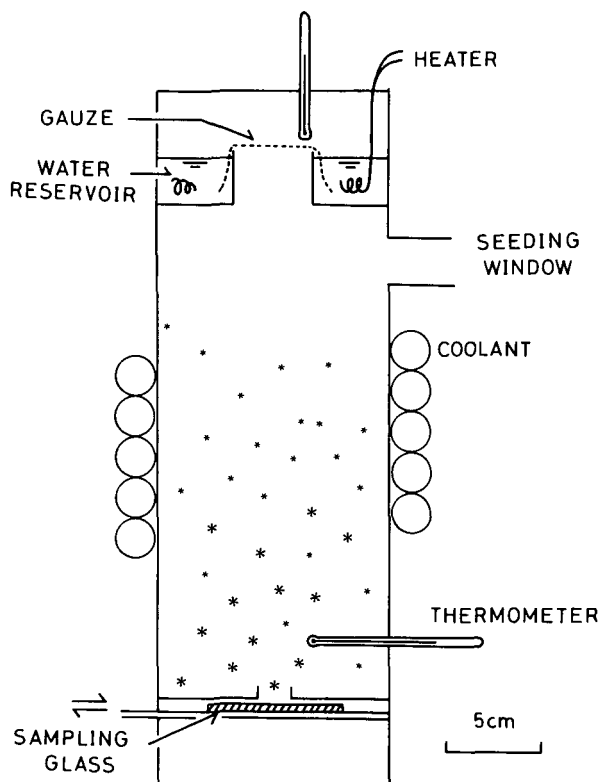


Fig. 6. Experimental apparatus.

of the droplets and seeding of AgI smoke were done from a seeding window at the upper part of the chamber. The maximal size of the AgI smoke particles measured by means of a scanning electron microscope was smaller than $0.3 \mu\text{m}$ in diameter.

Nucleation of the freezing of supercooled water droplets was done by one of three methods: (1) spontaneous nucleation was induced by inserting a fine metal rod previously cooled by liquid nitrogen into the chamber; (2) another spontaneous nucleation was accomplished by an adiabatic expansion bursting an air bubble made from thin polyethylene film; (3) contact or deposition nucleation was done by introducing AgI smoke. Ice crystals produced in the chamber were sampled by introducing a glass slide coated with silicone oil at the chamber bottom and were photographed using a polarization microscope. After that the artificial poly-snow germs were counted and classified as described previously.

Air temperature inside the chamber was read by means of thermometers at will.

3.2 Characteristics of single snow germs

Figure 7 represents one of experimental results of ice crystal habit at each temperature examined by the adiabatic expansion. In this figure, solid histograms shows a column type, and vertical stripe, dotted and open histograms show hexagonal plate, non-hexagonal plate and indistinct shape, respectively. Among the growth temperature range between -17 and -38°C in the adiabatic expansion examined, the percentage of the column type was 10% at the most. On the other hand, the percentages of hexagonal including non-hexagonal plate types to each nucleation method were 85%, 85% and 70% for the fine metal rod, adiabatic expansion and AgI smoke, respectively. A prevailing tendency of the hexagonal plate to column type in the relatively low temperature conditions was similar to the observational results by Kikuchi and Hogan (1979) at the South Pole, Antarctica and experimental ones by Gonda and Koike (1982). It is concluded that our experimental results correspond to the theoretical one by Kuroda and Lacmann (1982). However, we do not have any more consideration to the single ice crystals because of our attention was focused in the poly-snow germs.

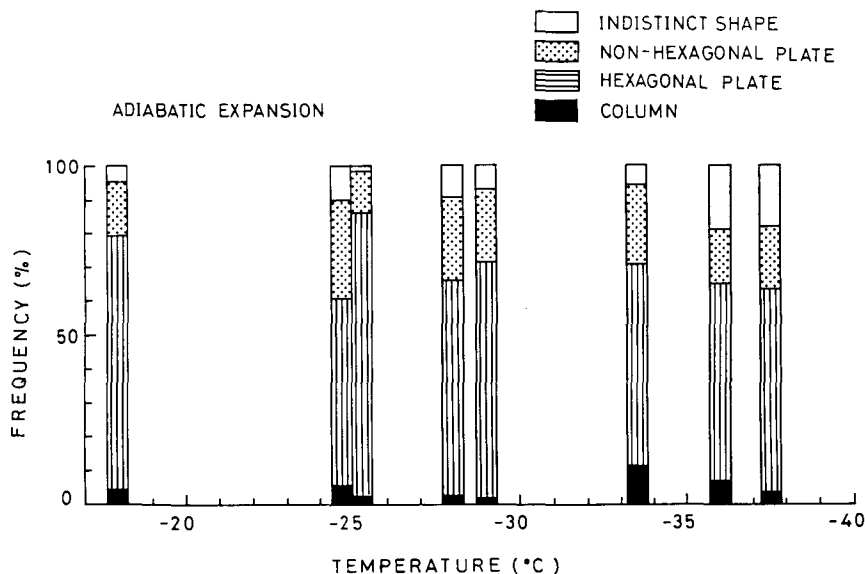


Fig. 7. Snow crystal habit and growth type with temperature by means of the seedings of adiabatic expansion.

3.3 *Morphology of artificial poly-snow germs*

In our experiments, we obtained a number of poly-snow germs as classified in the previous chapter. They showed no difference fundamentally between their morphology by different nucleation methods and growth temperatures. Figure 8 represents typical examples of artificial poly-snow germs. Figure 8(1) is the most typical one (pointed by arrow) classified as the type (a) in the previous chapter. Among the type (a), the poly-snow germ on which the secondary plate did not grow sufficiently was recognized as shown in Fig. 8(2). The germs of Fig. 8(3) and (4) correspond to the types of (b) and (d), and Fig. 8(5) and (6) to the types of (e) and (h), respectively. Furthermore, the examples of (7) and (8) are similar to those of the types of (i) and (j). Besides these poly-snow germs classified by Fig. 5, other types of germs which grow to the more complicate shapes were found in this experiment, for instance, as pointed out by arrows in Fig. 8(9) and (10). However, we could not find out the types of (f) and (g) in this experiments. Because these types have a different growth mechanism from others. For instance, they will be possible to grow alone under the condition of cubic structure twice in the initial stage of their nucleation. It is considered therefore that the possibility in which the mechanism originates in nature is extremely rare. Further, it is difficult to distinguish these from the types of (a) and (b), especially in the case of smaller germs. An example denoted on the lower right corner in the Fig. 8(3) results from an aggregation of germs with each other which was pointed out in an ice fog phenomenon at the Yellowstone National Park, U.S.A. by Magono and Tazawa (1972). These poly-snow germs described previously have a general characteristic in that they possess a common a -axis with each other. However, Fig. 9(1) seems to possess a common b -axis each other. And further, Fig. 9(2) seems to cross an a -axis of the elementary plate and b -axis of the secondary plate.

3.4 *Surface structure of snow germs in the initial stage of the growing process*

In the previous sections, we have considered the morphology of snow germs in the final stage of the growing process. As is well known, when supercooled water droplets were frozen to a single ice crystal, basal plane, pyramidal and prism faces are formed on their spherical surfaces firstly and next they grow snow germs of columns and plates through the shapes of twenty faces and fourteen faces. Then, we will describe the surface structure of ice germs especially in the initial stage of the growing process.

In the experiments using a fine metal rod and an adiabatic expansion

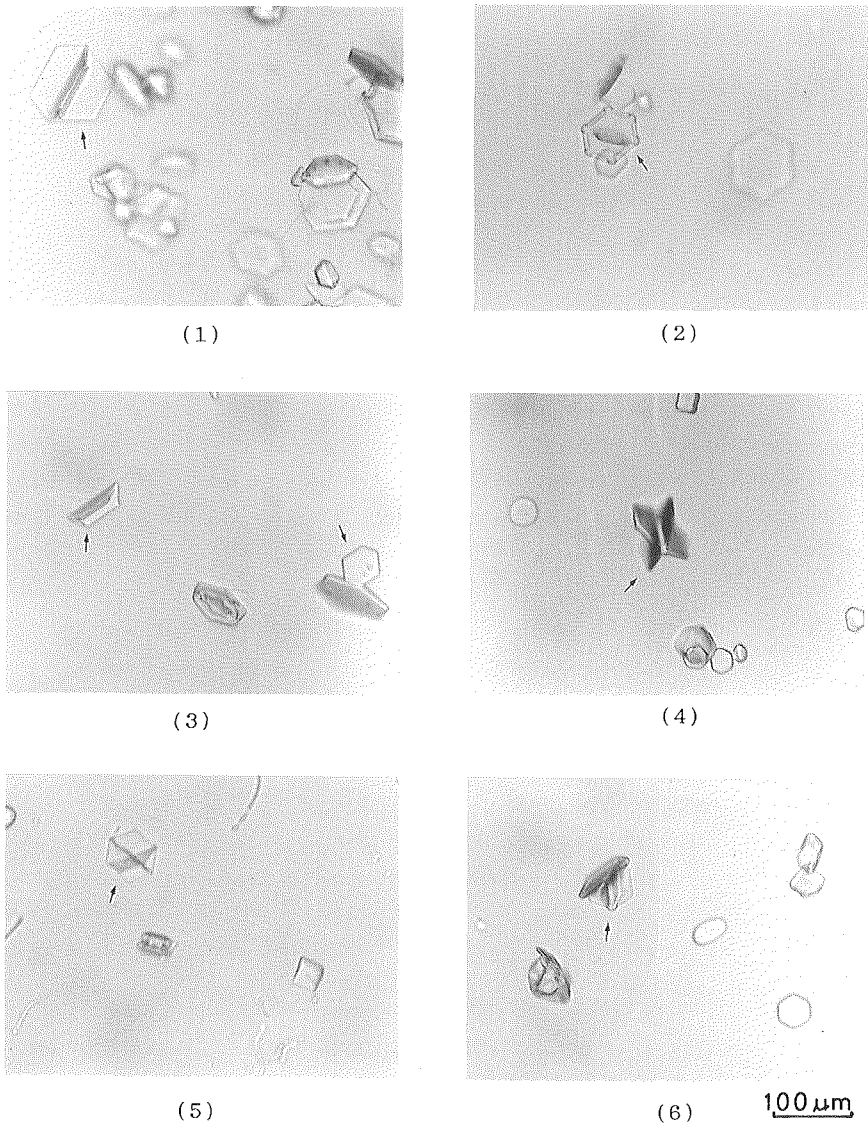


Fig. 8. Typical examples of the artificial poly-snow germs.

seeding, non spherical and rugged frozen droplets were formed and there was a tendency for the increasing production rate when the chamber temperature was decreased. Some of the rugged frozen droplets were clarified as poly-snow

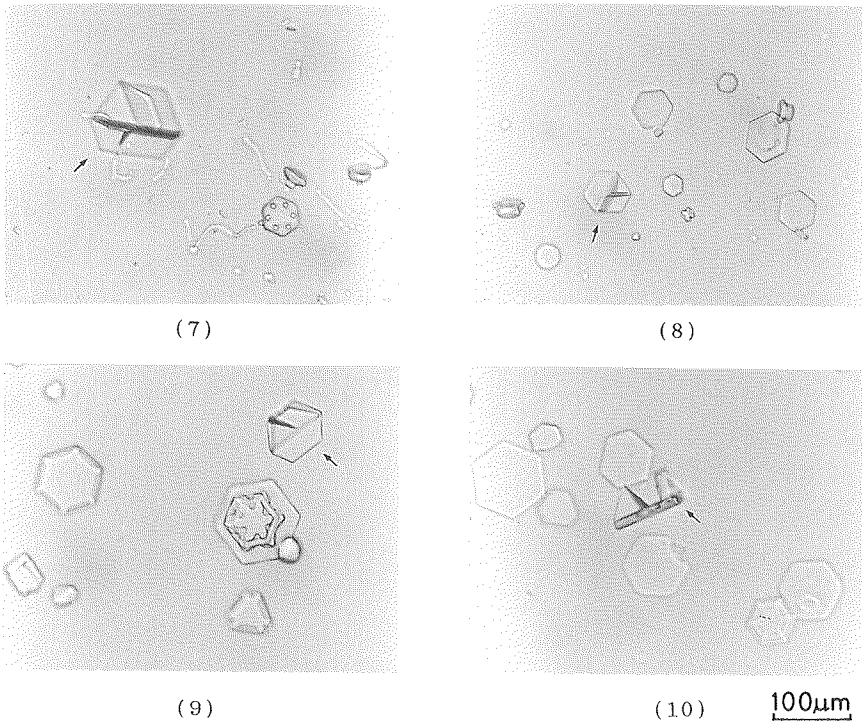


Fig. 8. (Continued).

germs by means of a polarization microscope. Scrutinizing the number of rugged frozen droplets, some of them did not appear as pyramidal and prism faces but as poly-snow germs of crossed plates types at the beginning. Figure 10 represents examples of these growing processes. The surface structure of snow germs as seen in Fig. 10(1) to (3) would grow secondary plates such as types (a) to (c), and Fig. 10(4) to that of types (i) and (j) in a similar manner.

3.5 Production rate of the artificial poly-snow germs

It has been considered that the factors affecting polycrystallization when the supercooled water droplets are frozen are supercooling, the size of droplets, diffusion of heat, the kind of nucleus and so on. And further, it is well known that the production rate of polycrystallization increases with the decrease of temperature. Thus, we examined the production rate of poly-snow germs to

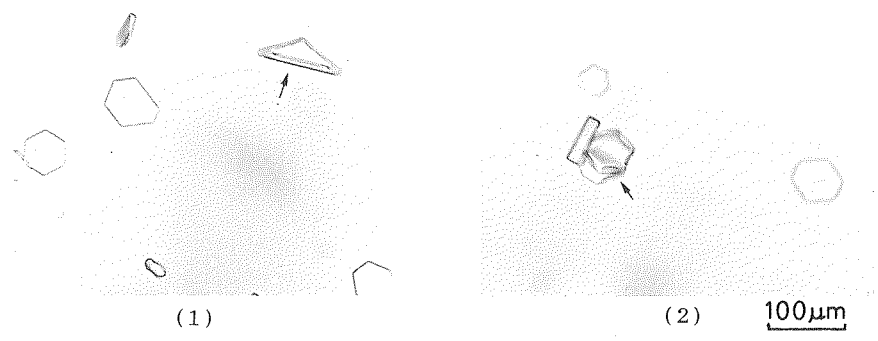


Fig. 9. Other examples of the artificial poly-snow germs.

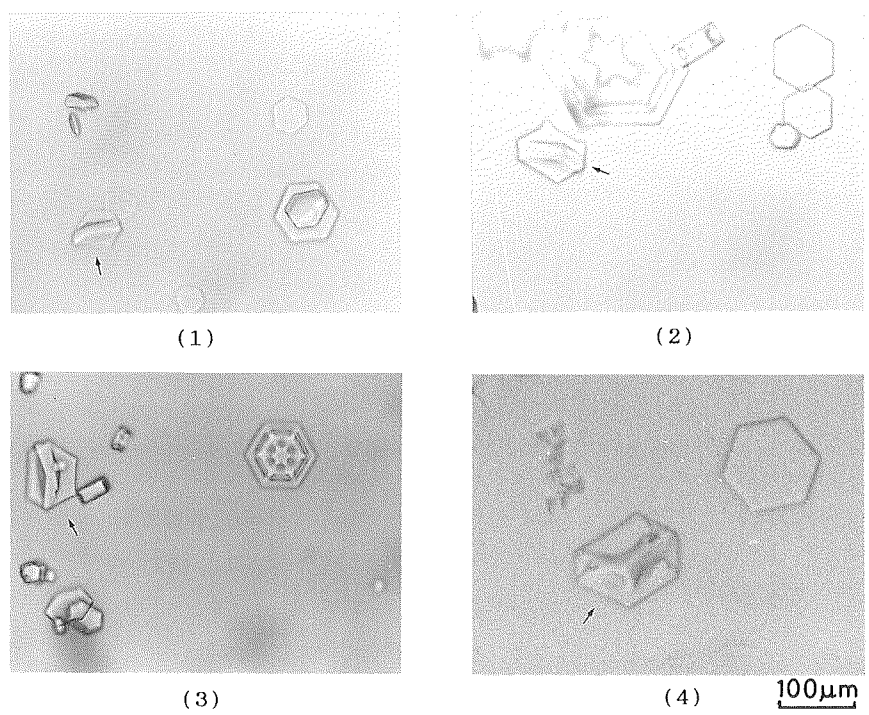


Fig. 10. Typical examples of the artificial poly-snow germs showing the growing processes of the secondary plate (1) to (3) and multiple plates (4).

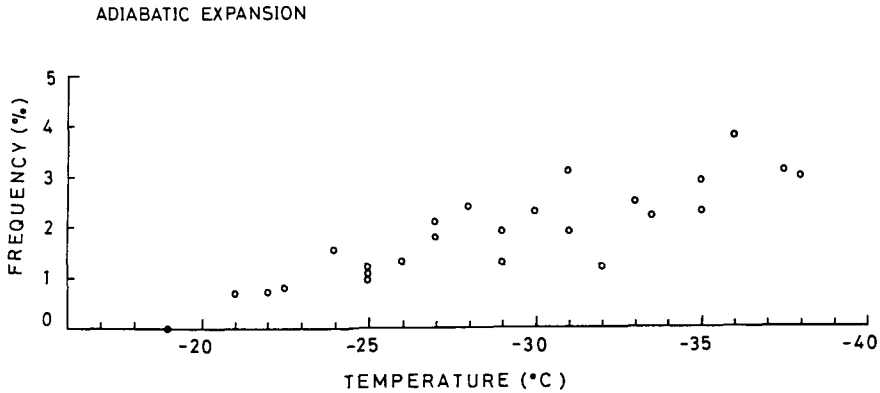


Fig. 11. Production rate of the artificial poly-snow germs by means of the seedings of adiabatic expansion.

about 500 particles in each seeding experiment. In the adiabatic expansion experiments, as a result, the poly-snow germs appeared at -20°C and they increased with the decrease of temperature as shown in Fig. 11. The production rate of them was less than 5% on the average. The percentage was similar to that of the previous observational ones and to that of snow crystals of low temperature types (peculiar shaped snow crystals) (Kajikawa et al., 1980). It is supposed therefore that they might be correlated with each other in their growing processes.

4. Concluding remarks

From among a number of microphotographs of ice and snow crystals taken in the ice needle and ice fog phenomena in the Arctic and Antarctic regions, polycrystalline snow germs (poly-snow germs) were selected and they were classified into the types as shown in Fig. 5. The percentage of the simplest types of (a) to (d) indicated 60% on the average. The angle between each component plate of poly-snow germs, that is to say, the elementary plate and secondary plate was estimated as 70.5° and 109.5° for the supplementary angle. The experiments to reproduce these poly-snow germs in our laboratory were carried out by means of AgI smoke, adiabatic expansion and chilled fine metal rod seeding into supercooled water droplets under the temperature conditions between -18 and -42°C . As a result, we obtained a number of poly-snow germs of all kinds classified previously except types (f) and (g). The reason for

this is because the types (f) and (g) could not be found in our experiments, leads to the following difficulties; Firstly, they have a different growth mechanism from others such as the condition of cubic structure twice in the initial stage of their nucleation. The possibility that the mechanism originates in nature is extremely rare. Secondly, it results from a difficulty to distinguish them from types (a) and (b), especially in smaller germs. These poly-snow germs had general characteristics in which they possessed a common a -axis with each other. However, different examples in which they seem to possess a common b -axis with each other were obtained. Furthermore, in the experiments by a fine metal rod and adiabatic expansion seedings, non-spherical and rugged frozen droplets were formed and some of them were classified as poly-snow germs by means of a polarization microscope. Scrutinizing a number of rugged frozen droplets, they seem to grow without the appearance of the pyramidal and prism faces but poly-snow germs of crossed plates types at the beginning. The surface structure of snow germs as seen in Fig. 10(1) to (3) would grow to the secondary plate such as types (a) to (c) and Fig. 10(4) to that of types (i) and (j), respectively. The production rate of poly-snow germs in these experiments was less than 5% on the average. This value was similar to that of the observational results. As one of the growth mechanisms of these poly-snow germs, the cubic structure model which was introduced into the nucleation process of snow polycrystals by Furukawa (1982) might be possible.

Acknowledgments

The microphotographs used in this paper were collected when one of the authors (K.K.) was a member of the summer party of USARP, NSF at the South Pole Station, Antarctica, and was one of the members of the Overseas Scientific Survey and Polar Experiment (POLEX) North in the Arctic Canada, and further, Kikuchi and Uyeda were members of the Northern Norway Project and the Greenland Project of the International Scientific Research Program. The Overseas Scientific Survey and the International Scientific Research Programs were supported by Funds for Scientific Research from the Ministry of Education, Science and Culture of Japan.

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