ICE CRYSTALS GROWN FROM THE VAPOR AT TEMPERATURES LOWER THAN −15°C

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Abstract: By analyzing photomicrographs, the nature of ice crystals grown at temperatures lower than −15°C was studied first. It was found that in the initial stage of growth, the frequency of occurrence of single-crystalline ice decreases as the temperature decreases although the type of nuclei and method of seedings affects it considerably, and that at temperatures below about −17°C, the lower the temperature the greater the growth rate of polycrystalline ice as compared to that of single-crystalline ice. Second, large ice crystals were grown in an unforced air flow cloud chamber and the nature of polycrystalline ice growing at temperatures lower than about −20°C was investigated with the following findings: the most prominent polycrystals are those with a sharp growing tip and having a few or many side branches; the most abundant polycrystals are those having a smaller growth rate than the former and being composed of a single or several radially grown branches of assemblages of plates, columns or irregular crystals; radially grown polycrystals are very fragile.

1. Introduction

Polycrystalline snow crystals have attracted interest in the study of cloud physics and crystal growth only in the last fifteen years, in spite of their frequent occurrence in natural clouds; as a result, experiments focusing on growing polycrystalline ice from the vapor have been tried quite recently (TAKAHASHI, 1983; SATO and KIKUCHI, 1983). However, little is known about the effect of nuclei or seeding method on the formation of ice polycrystals; detailed features of various polycrystals of ice, their growth rates and individual growth mechanisms have also been little investigated.

In previous experimental studies YAMASHITA (1971, 1973, 1974) has shown the crystal habit of single crystalline ice quantitatively and has shown several types of nonhexagonally shaped single-crystalline or polycrystalline ice. Most of photomicrographs of these ice crystals and other polycrystals, however, have not been analyzed. The present paper first describes analyses of ice crystals in these previous experiments, and second ice crystals grown in an unforced air flow cloud chamber, which was designed by YAMASHITA and OHNO (1984), at comparatively low temperatures.

2. Single-Crystalline and Polycrystalline Ice Grown in Free Fall

In previous experiments (YAMASHITA, 1971, 1973, 1974), ice crystals were nucleated in a supercooled cloud by various seedings; most photographed ice crystals were grown for 200 s in a supercooled cloud. These were reexamined for the purpose of research on the nature of polycrystalline ice.

Percentages of single-crystalline ice shown in Fig. 1 were obtained from about ten thousand photomicrographs of ice crystals. This shows that the types of nuclei and the methods of seedings have a serious effect on the formation of polycrystalline ice; the higher the temperature the smaller the amount of polycrystalline ice. In these seedings, *i.e.*, AgI (smoke), adiabatic cooling by popping polyethylene film enclosing a small volume of air (about 0.25m*l*), dry ice and bentonite, almost all polycrystals were assemblages of plates (spatial plates) or spatial dendrites. The mass growth rate of single-crystalline ice in Fig. 2 was obtained by measuring the sizes of spherical water droplets formed by melting ice crystals in silicone oil. This indicates that at temperatures lower than −15°C the lower the temperature the smaller the mass growth rate of single-crystalline ice in spite of the higher supersaturation in a supercooled cloud. The growth rate shown in Fig. 3 was obtained by measuring the largest sizes of polycrystals from the photomicrographs; the size was divided by 2 because the crystal was inferred to have grown having two ends growing in opposite directions and, then, divided by 200 s in order to obtain the growth rate per second. Growth rates of V-shaped ice crystals and single-crystalline ice are also shown in the figure for comparison. It is clear that at temperatures lower than about −17°C the growth

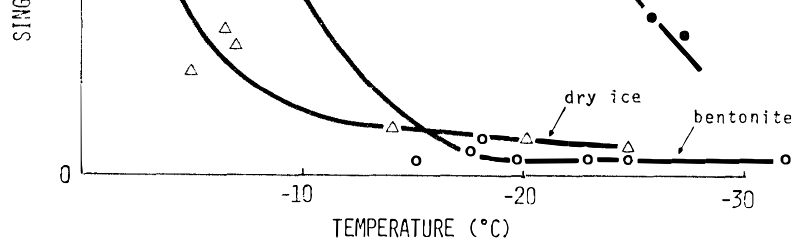

Fig. 1. Percentages of single-crystalline ice germinated by various seedings and grown in free fall for 200 s in a supercooled cloud. AgI (smoke): silver iodide smoke generated by heating a small amount of AgI using a micro-heater in the cloud; adiabatic cooling: popping polyethylene film enclosing a small volume (0.25 ml) of air; dry ice: a method to introduce a pellet of dry ice for about 1/4 s; and bentonite; a method to seed fine particles of bentonite (Tone bentonite) (for further details refer to YAMASHITA, 1974).

rate of assemblages of plates or dendrites is greater than those of single-crystalline ice, although the value fluctuates considerably from crystal to crystal. The growth rate of some V-shaped ice crystals grown at temperatures about $-18 \sim -20$°C is especially great and exceeds even that of dendrites grown at about -15°C. V-shaped ice crystals, however, have only two prominent growing tips.

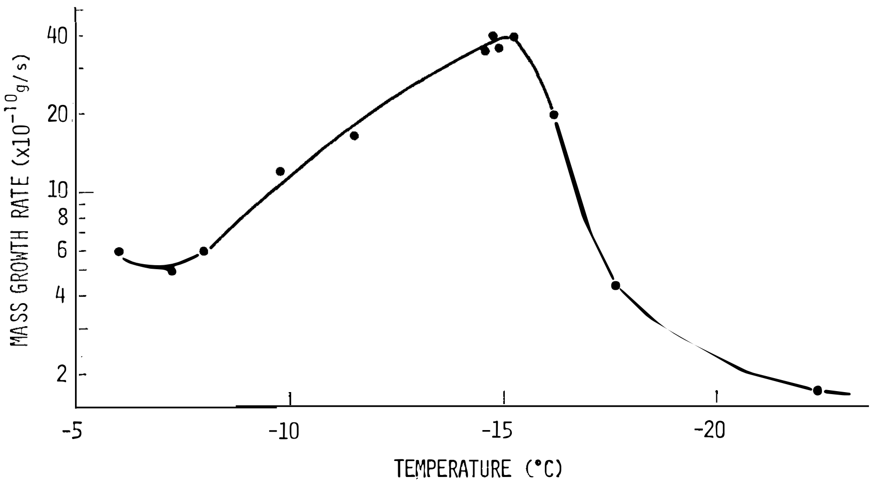

Fig. 2. Mass growth rate of single-crystalline ice in previous experiments (YAMASHITA, 1973, 1974).

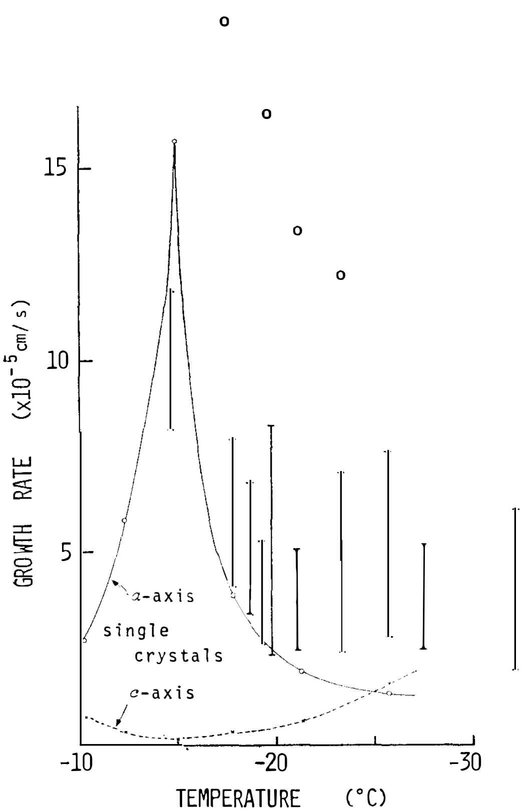

Fig. 3. Growth rates of polycrystalline ice calculated using the data obtained in previous experiments (YAMASHITA, 1973, 1974). Growth rates of the assemblage of plates (spatial plates) and spatial dendrites are shown by vertical lines; those of the V-shaped crystals are shown by open circles. a- and c-axes growth rates of single-crystalline ice in the experiments are also shown.

3. Polycrystalline Ice Grown in an Unforced Air Flow Cloud Chamber

Preliminary experiments to grow ice crystals in an unforced air flow cloud chamber (YAMASHITA and OHNO, 1984) at temperatures lower than −15°C were carried out in the Low Temperature Laboratory of the National Institute of Polar Research. It was found that polycrystalline ice crystals can be grown at temperatures between −17 and −38°C. The main experiments were carried out in a comparatively small unforced air flow cloud chamber (inside volume 22 *l*) placed in another unforced air flow cloud chamber (inside volume 217 *l*). When both chambers were operated continuously for days, temperatures in the small chamber became very low as shown in Fig. 4, and it was found that ice crystals can be grown on threads suspended vertically or on hard frost in the chamber. Although a supercooled cloud is observable at the level where ice crystals grow large, comparatively small ice crystals are also observable at levels slightly higher or lower than that of a supercooled cloud.

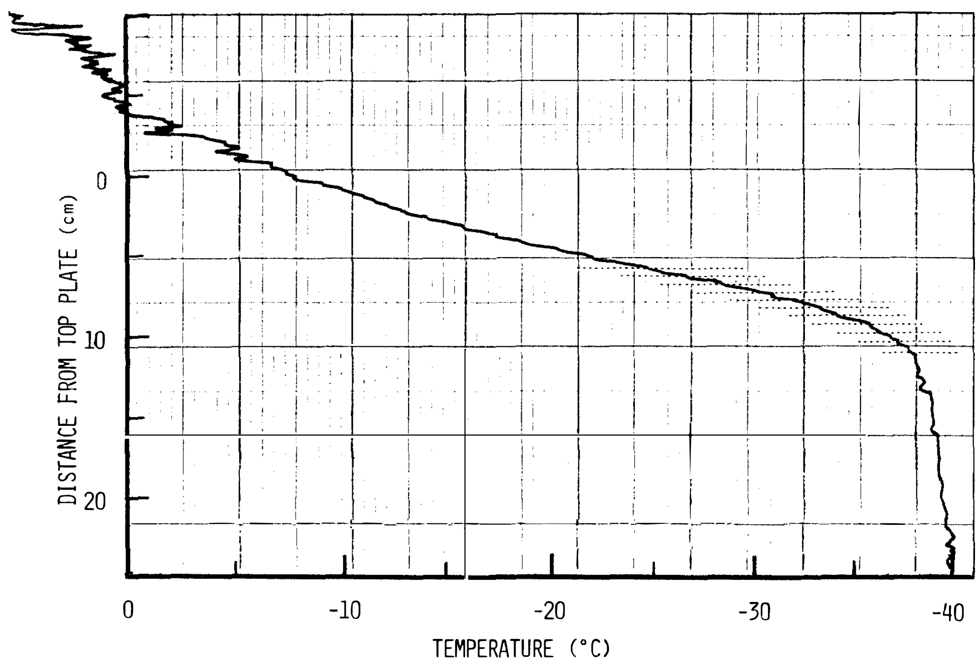

Fig. 4. Typical temperature profile in an unforced air flow cloud chamber set in another large sized unforced air flow cloud chamber for the purpose of growing ice crystals at low temperatures. Small dots show levels where ice crystals were grown.

In the present study only prominent ice crystals as shown in Figs. 5 and 6 were studied because numerous small ice crystals were only about 1/5–1/50 of the prominent ice crystals. The crystal shown in Fig. 5a is an assemblage of plates and columns grown almost straight from thread; the detailed construction of this type of crystal is shown in Fig. 8a. Those in Figs. 5b and 5c are assemblages of plates, columns and irregular crystals grown almost radially from a central assemblage of plates and columns (b) or from a polycrystal with a sharp tip (c); their detailed construction is similar to each other (Fig. 7). The most outstanding crystals were those having a

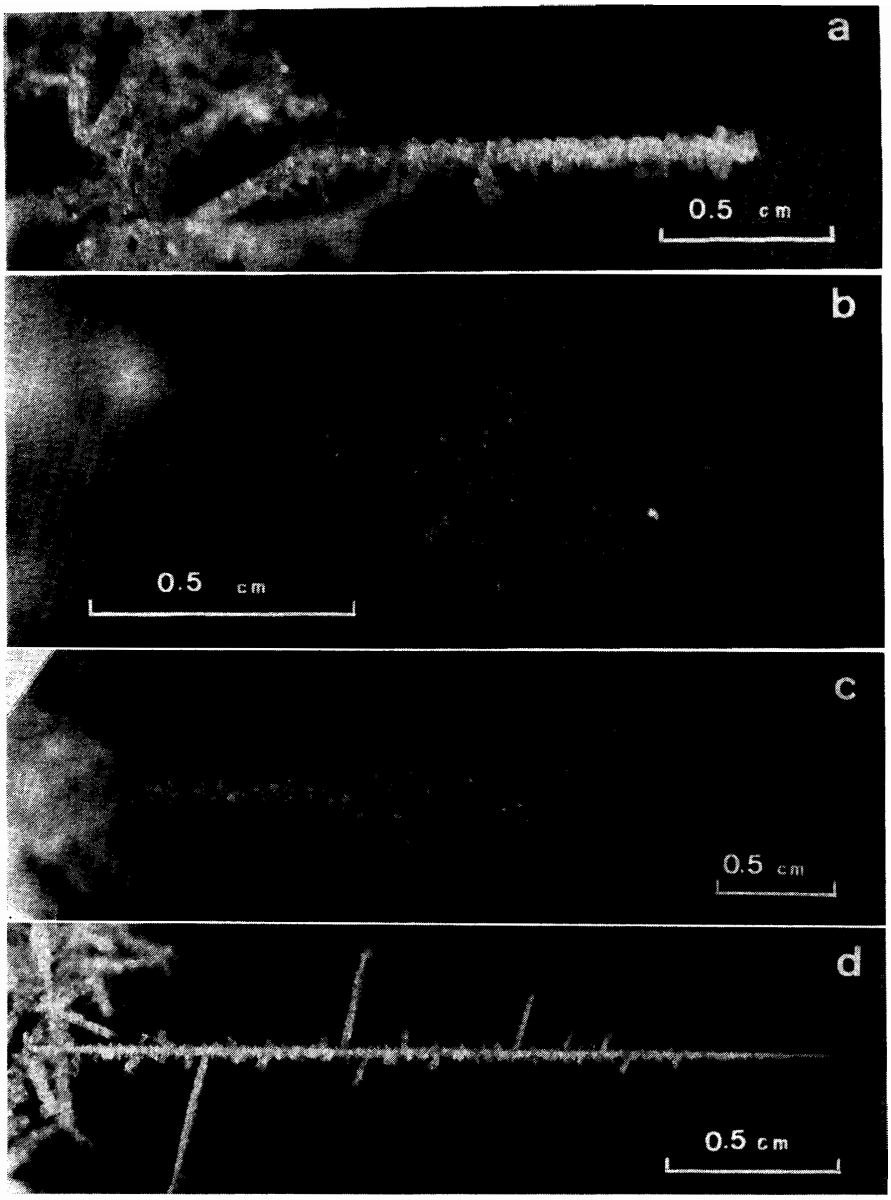

Fig. 5. Prominent ice crystals grown on thread (a and b) or on hard frost (b and c) in an unforced air flow cloud chamber. a: an assemblage of plates and columns growing straight, −24∼−25°C, b: assemblages of plates, columns and irregular crystals growing radially from the central assemblages of plates and columns, −31°C, c: assemblages of plates, columns and irregular crystals growing radially from a polycrystal with a sharp tip, −22∼−23°C, d: polycrystalline ice with a sharp growing tip having side branches, −23∼−25°C. These were photographed directly in the chamber after being grown for about 40 hours.

sharp tip and a few groups of parallel branches; most of these branches had sharp tips. Figures 5d and 6 give examples of this type of ice crystal and their detailed constructions are also shown in Figs. 8b and 8c. This type of crystal has the largest growth rate among these prominent ice crystals; however, the growth rate varied widely from crystal to crystal between 1×10^{-5} and 5×10^{-5} cm/s, maybe because ice

Fig. 6. *A prominent ice crystal grown on hard frost in an unforced air flow cloud chamber (a polycrystal with a sharp growing tip having many side branches). This was photographed directly in the chamber after being grown for 40 hours at $-22 \sim -23^{\circ}C$.*

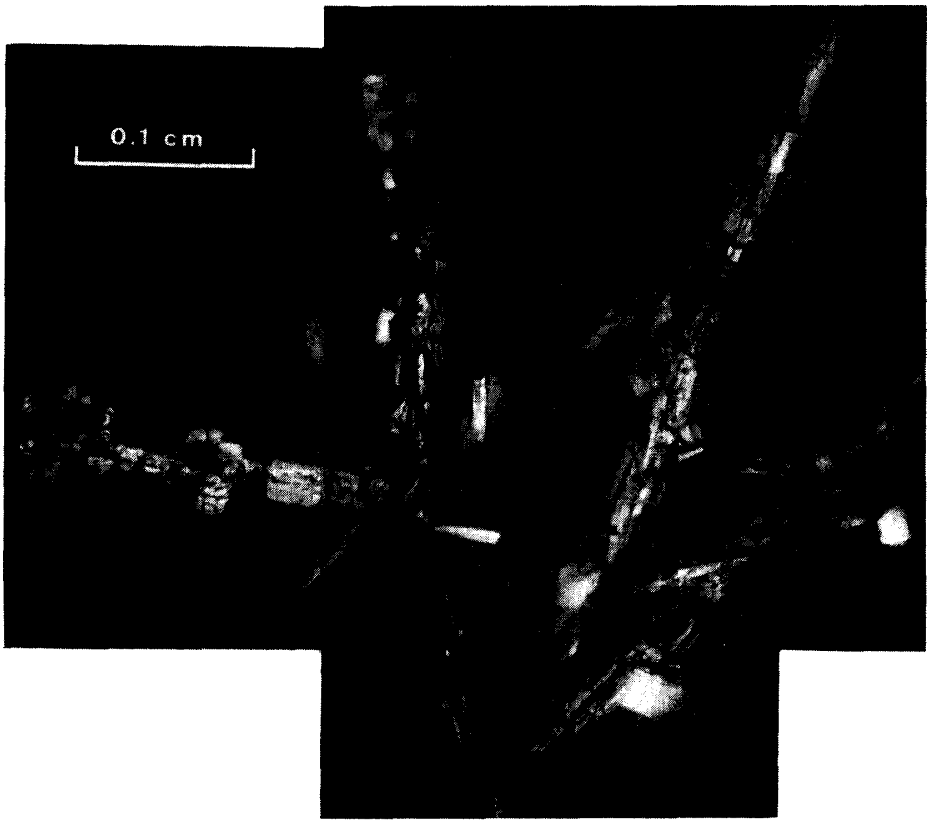

Fig. 7. *Detailed structure of the ice crystal shown in Fig. 5b. This was photographed under a polarization microscope (in color).*

crystals having different sharp tips grew into similar appearing crystals. The other types grew at about half the speed of the most outstanding crystals. Those assemblages of plates, columns and irregular crystals which had grown radially were so fragile that they could not be sampled on a glass slide without damaging their three dimensional frames. Among two hundred polycrystals observed in these experiments no crystals differed greatly in shape from those shown in Figs. 5 and 6.

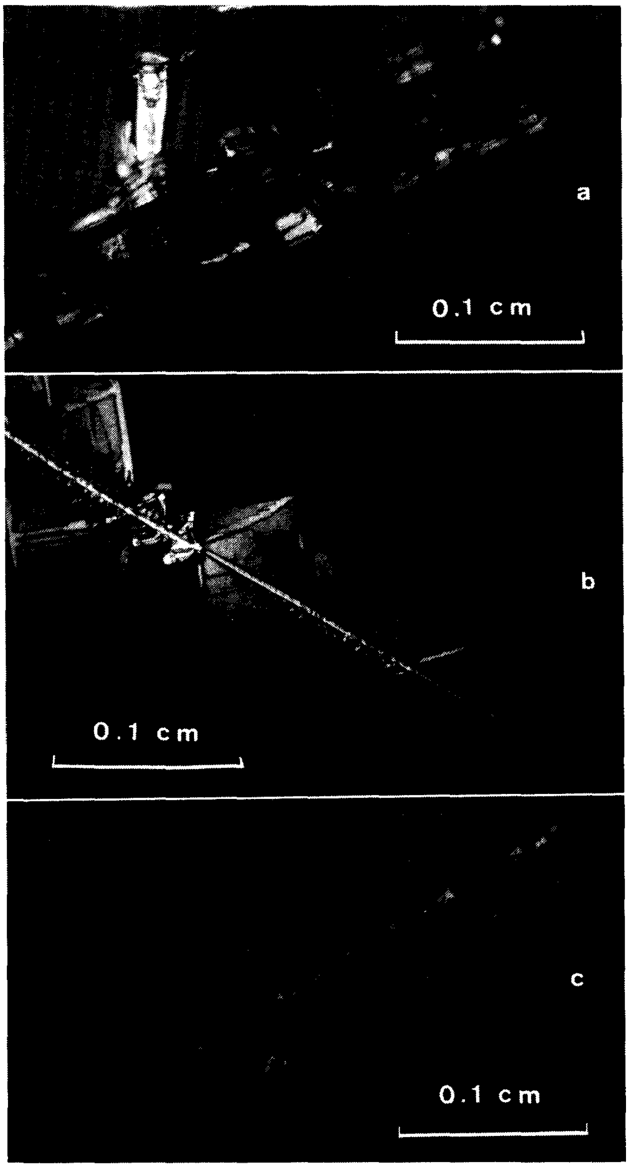

Fig. 8. Detailed structures of polycrystals photographed under a polarization microscope (in color).
a: the crystal shown in Fig. 5a, −24∼−25°C,
b: a crystal with a sharp growing tip, −28°C,
c: a crystal with a sharp growing tip having side branches, −31°C.

4. Discussion and Concluding Remarks

In the free fall experiments both single-crystalline ice and polycrystalline ice were observed although their percentages depended considerably not only on temperatures but also on the types of nuclei and the method of seedings. These ice single crystals, however, might subsequently grow into polycrystals if they could be grown more than 200 s. In an unforced air flow cloud chamber, on the other hand, prominent ice crystals were all polycrystals; perhaps single crystals grew so slow even in a supercooled cloud that they seemed to be almost completely veiled by prominent polycrystals.

The most abundant polycrystals in the free fall experiments, assemblages of plates (spatial plates), are the same type of crystals as assemblages of plates, columns and irregular crystals (cf. Figs. 5a, 5b, 5c, 7 and 8a) grown in an unforced air flow cloud chamber. V-shaped ice crystals in the former free fall experiments seem to be morphologically identical to those polycrystals having pointed tips (cf. Figs. 5d, 6, 8b and 8c) although the number density of pointed parts around the periphery of the V-shaped ice crystals is about 10–50 times greater. For the present, however, the effect of ventilation due to falling motion of snow crystals has been studied little even at temperatures higher than −15°C. Therefore, quantitative comparison of these two kinds of experiments should be left to the future.

The fragile construction of radially grown polycrystalline ice should be studied quantitatively because the breaking of the fragile crystals may contribute to the secondary production of ice crystals in natural clouds. Detailed classification of ice polycrystals accompanied with detailed observations of their structures, experiments to disclose their germinations and observations of their growth rates should be tried in the future in order to understand the nature of snow crystals growing at temperatures lower than about −15°C.

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