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MORPHOLOGICAL INSTABILITY OF POLYHEDRAL ICE CRYSTALS GROWING IN AIR AT LOW TEMPERATURE

by

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ABSTRACT

The morphology of snow crystals growing at a low temperature has been experimentally studied. The habit and the morphological instability of the crystals vary remarkably with air pressure. In addition, the morphological instability of the crystals depends not only on air pressure but also on supersaturation, crystal size, the ratio of growth rates and the ratio of axial lengths. It is supposed from the experimental results that long prisms with small skeletal structures forming at low supersaturation are precipitating in polar regions.

INTRODUCTION

Snow crystals forming in polar regions are roughly classified into single- and poly-crystals. In these crystals, polycrystalline snow crystals have been studied by Kikuchi (1970), Kobayashi and Furukawa (1976) and Kobayashi and others (1976). Single snow crystals such as long solid prisms (Shimizu 1963) and diamond dust type ice crystals (Kikuchi and Hogan 1979) which have been observed in Antarctica, and rectangular snow crystals (Higuchi 1968) observed at Barrow, Alaska, have been studied experimentally by Gonda and Koike (1982), Gonda (1983) and Gonda and others (1984). In addition, Sato (1983) and Wada and Gonda (1985) have reported that long prisms with skeletal structures had been observed in Antarctica. These peculiar snow crystals have been observed only rarely in Japan.

On the other hand, theoretical investigations on the morphological instability of a polyhedral crystal have been done by Kuroda and others (1974) and Kuroda (1982). The first purpose of this article is to clarify experimentally the factors controlling the morphological instability of polyhedral ice crystals growing at low temperature. The second is to clarify the formation mechanism of snow crystals forming in polar regions, especially long prisms with skeletal structures.

EXPERIMENTAL PROCEDURES

Details of a growth chamber have been described in a previous paper (Kuroda and Gonda 1984). The chamber is designed to cool independently an ice plate for supplying water vapor and a substrate for the growth of ice crystals, inserting a thermal insulator between the upper and the lower plates. To keep the ice plate and the growth substrate at constant temperatures, electric current flowing to the thermoelectric cooling panels attached at the upper and lower plates is automatically turned on and off, using two temperature regulators. By these operations, the accuracy in the temperatures on the ice plate and the growth substrate is kept within ± 0.05 °C.

Water vapor is supplied by keeping the ice plate at slightly higher temperature than that on the growth substrate. Ice crystals are nucleated in air by inserting about 3 cm^3 of diluted silver iodide smoke into the growth chamber. Minute ice crystals nucleated in air fall in a short time on the growth substrate. Ice crystals were grown in air at 4.0×10^3, 3.3×10^4 and 1.0×10^5 Pa at -30 °C and various constant supersaturations, and we observed the growing ice crystals *in situ* using a differential interference microscope.

EXPERIMENTAL RESULTS

Figure 1 shows an ice crystal grown in air at 4.0×10^3 Pa at -30 °C and a supersaturation of 5.8%. As shown in Figure 1, the columnar ice crystal with small skeletal structures grows in air at 4.0×10^3 Pa, while Gonda and Koike (1983) produced a polyhedral plate-like ice crystal in air at 4.0 x 10 Pa at the same temperature and supersaturation. The upper (0001) face of the columnar ice crystal grows stably in early stages (a) but becomes unstable with time (b). The (0001) face becomes stable again later (c) and the skeletal structure on the (0001) face is contained inside the crystal as air bubbles (d, e and f). Afterward, the same phenomenon takes place on the lower (0001) face of the crystal. Why the surface instability does not come out symmetrically on both the (0001) faces may be due to a slight difference of the forward velocity of steps towards a center of the crystal on both the (0001) faces for some reason or another.

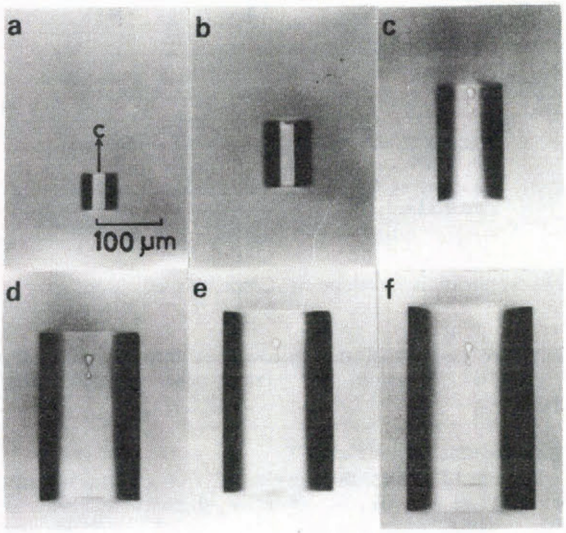

Fig.1. Columnar ice crystal grown in air at 4.0×10^3 Pa at -30 °C and a supersaturation of 5.8%: (a) 4.3 (b) 9.1 (c) 21.5 (d) 39.5 (e) 46.6 (f) 63.4 min.

Figure 2 shows an ice crystal grown in air at 1.0×10^5 Pa at -30 °C and a supersaturation of 5.8%. The ice crystal grown in air at 1.0×10^5 Pa grows along the c-axis longer than that at 4.0×10^3 Pa, and a long prism is formed. At the same time, skeletal structures (d, e and f) larger than those at 4.0×10^3 Pa are formed on the upper and lower (0001) faces of the crystal. The (0001) face of the crystal grown in air at 1.0×10^5 Pa is kept at unstable growth even when the crystal size has grown considerably.

Figure 3 shows the instability limits of the (0001) face of columnar ice crystals grown in air at 4.0×10^3, 3.3×10^4 and 1.0×10^5 Pa at -30 °C. Here the crystal size is the length along c-axis of ice crystals. As shown in the figure, the instability limits of ice crystals depend not only

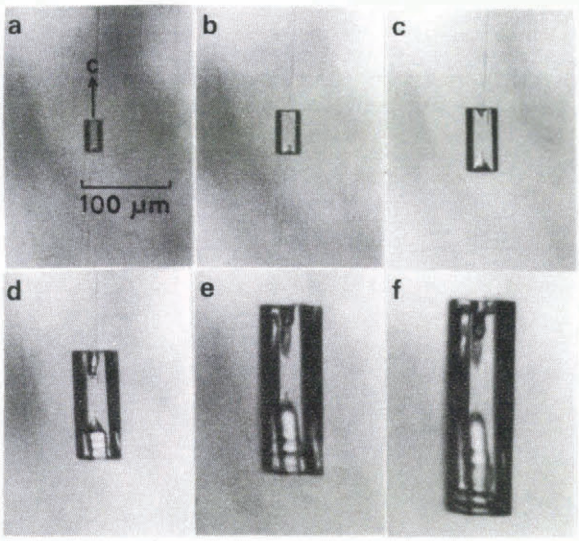

Fig.2. Columnar ice crystal grown in air at 1.0 x 10^5 Pa at -30°C and a spuersaturation of 5.8%: (a) 3.3 (b) 8.8 (c) 18.4 (d) 47.0 (e) 98.2 (f) 141.4 min.

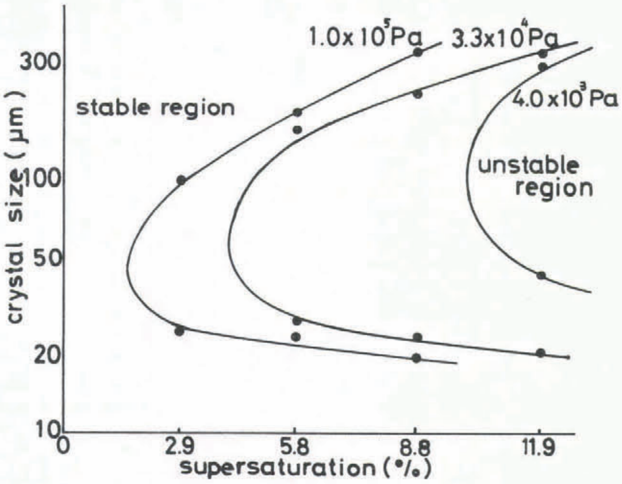

Fig.3. Instability limits of the (0001) face of columnar ice crystals grown in air at 4.0 x 10^3, 3.3 x 10^4 and 1.0 x 10^5 Pa at -30°C.

on supersaturation and crystal size (Gonda and Koike 1982, 1983) but also on air pressure. Especially, it is seen that the unstable region becomes large when the air pressure is high and small when it is low. The habit of ice crystals is closely related to the morphological instability of the crystals (Gonda and Namba 1981). That is, long prisms with skeletal structures grow when air pressure is high, while polyhedral plate-like crystals grow when air pressure is low.

Figure 4 shows the relations between the ratio of growth rates R_b / R_p and the ratio of axial lengths c/a of ice crystals grown in air at (a) 3.3 x 10^4 and (b) 1.0 x 10^5 Pa at -30°C when the instability occurs first on either the (0001) or the (1010) faces, solid and open circles, respectively. As shown in Figure 4, the morphological instability of the crystals depends not only on air pressure, supersaturation and crystal size but also on the ratio of growth rates and the ratio of axial lengths.

DISCUSSION

To clarify factors controlling the morphological instability of snow crystals growing at a low temperature, and to infer the formation mechanism of snow crystals forming in polar regions, especially long prisms with skeletal structures, ice crystals have been grown in air at 4.0 x 10^3, 3.3 x 10^4, and 1.0 x 10^5 Pa at -30°C and various constant supersaturations. As a result, it has been found that the air pressure plays a very important role in both the habit change and the morphological instability of ice crystals. That is, polyhedral plate-like ice crystals grow in air at 4.0 x 10 Pa at -30°C, while column-like ice crystals with skeletal structures grow in air above 4.0 x 10^3 Pa at -30°C. The higher the air pressure, the longer prismatic columns with large skeletal structures grow.

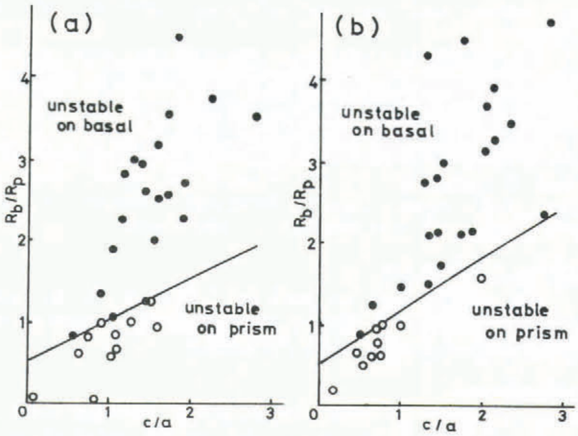

Fig.4. The relations between the ratio of growth rates R_b/R_p and the ratio of axial lengths c/a of ice crystals of 80 μm grown in air at (a) 3.3 x 10^4 and (b) 1.0 x 10^5 Pa at -30°C when the instability occurs first on either the (0001) or the (1010) faces. R_b and R_p show the growth rates of the (0001) and (1010) faces respectively. a and c show the lengths along a- and c-axes of ice crystals respectively.

Morphological instability of ice crystals depends not only on air pressure but also on supersaturation, crystal size, the ratio of growth rates of the (0001) and the (1010) faces and the ratio of axial lengths. Instability depends on the factors described above because the shape of diffusion field of water molecules around the crystals and the thickness of the diffusion layer depend on these factors. Consequently, morphological instability of the crystals is explained in terms of inhomogeneity in supersaturation at the crystal surface.

Many long prisms with skeletal structures precipitating in polar regions are explained by the rise and fall in supersaturation. However (Figure 3), the lowest supersaturation at which the morphology of ice crystals growing in air at 4.0 x 10^3 Pa at -30°C becomes unstable is about 10.1%; in air at 3.3 x 10^4 Pa at -30°C, it is about 4.1%, while in air at 1.0 x 10^5 Pa at -30°C, it is about 1.7%. That is to say, the lowest supersaturation at which the morphology of ice crystals becomes unstable decreases with increasing air pressure. On the basis of *in situ* observations of ice crystal surfaces growing in air at 1.0 x 10^5 Pa at -30°C, using a Video tape recorder, it has been found that at a supersaturation below a few %, long prisms with skeletal structures are formed when screw dislocations emerge near the corners of the (0001) faces of the crystals. It has also been found that long solid prisms grown when screw dislocations emerge near a center of the (0001) faces of columnar crystals under the same growth condition. That is, the formation of long prisms with or without skeletal structures depends on whether screw dislocations emerge near the corners or near a center of the (0001) faces. The reason why long prisms with and without skeletal structures are both observed in polar regions at relatively low supersaturation will be explained by our experimental results. Details of this experiment will be published in the near future.

CONCLUSIONS

The morphological instability of ice crystals grown in various constant air pressures at -30°C and various constant supersaturations has been studied. The results obtained are as follows.

1) Air pressure plays a very important role in both the

habit change and the morphological instability of ice crystals.

2) Morphological instability depends not only on air pressure but also on supersaturation, crystal size, the ratio of growth rates and the ratio of axial lengths. The experimental results are finally explained in terms of inhomogeneity in supersaturation at the crystal surface.

3) It is supposed from the experimental results that long prisms with small skeletal structures forming at low supersaturation are precipitating in polar regions.

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