—研究論文—
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Snow Crystals of Hollow-prism Type Observed at Mizuho Station, Antarctica

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南極みずほ基地で観測した骸晶構造を持つ角柱結晶

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要旨：1979 年 3 月から 1980 年 1 月まで南極みずほ基地で雪結晶の顕微鏡観測を行った．種々の形の雪結晶の中に，骸晶構造を持つ角柱結晶が，比較的多く降っていることがわかった．この論文では，この結晶の結晶学的諸特性と成長条件を議論する．

Abstract: The observations of snow crystals have been made using a stereoscopic microscope at Mizuho Station, Antarctica during March 1979 and January 1980. Hollow prisms were observed rather in excess together with different shapes of snow crystals. Crystallographic properties and growth conditions of hollow prisms are discussed in this paper.

1. Introduction

In the 1960's, the studies of snow crystals growing at such low temperature as air temperature in polar regions were made by turning our attention to single snow crystals, that is, long solid prisms (SHIMIZU, 1963), ice whiskers (KOBAYASHI, 1965) and rectangular crystals (HIGUCHI, 1968). In the 1970's, the observations of polycrystalline snow crystals at Antarctica (KIKUCHI, 1970; KIKUCHI and YANAI, 1971; KIKUCHI and HOGAN, 1976, 1979) and the theoretical studies of them (KOBAYASHI, 1965; KOBAYASHI *et al.*, 1976; TAKAHASHI, 1982) were actively made. In the 1980's, single snow crystals growing in polar regions have attracted again the attention of our groups and the growth mechanisms of them have been studied (GONDA and KOIKE, 1982; GONDA, 1983; GONDA *et al.*, 1984; GONDA and GOMI, 1985).

Only a few studies of single snow crystals forming below −20°C have been made till the present; therefore, new types of snow crystals which were not observed by KLINOV (1960), KIKUCHI (1974) and so on, for example, long prisms with many air bubbles inside the crystals (GONDA *et al.*, 1985) may be found in polar regions. In this paper, the crystallographic properties and the growth conditions of hollow prisms observed at Mizuho Station, Antarctica during March 1979 and January 1980 are described.

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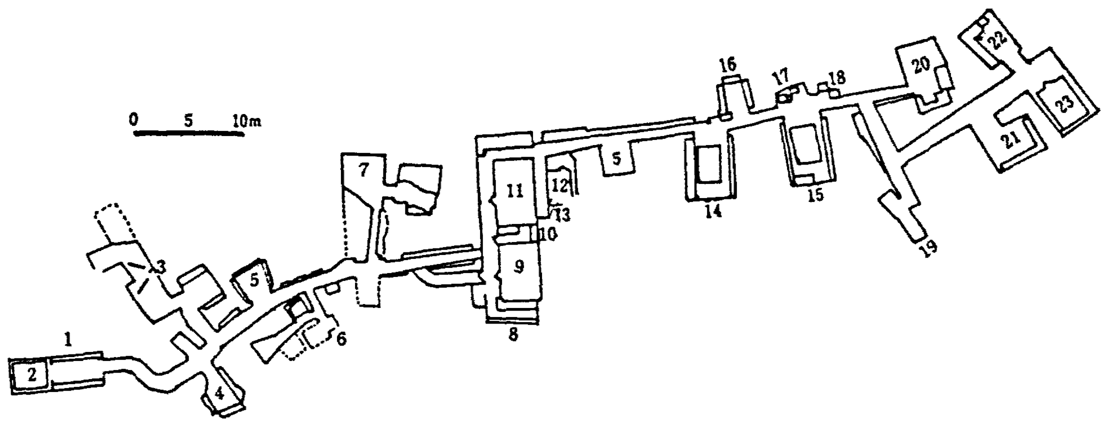

Fig. 1. Plan of Mizuho Station, Antarctica. Each number in the figure shows the room number.

2. Method of Observation

Figure 1 shows the plan of Mizuho Station which is built under snow surface. The katabatic winds above 10 m/s blow frequently at Mizuho Station. Since it is difficult to collect falling snow crystals when the wind is strong, the collection was carried out at the time of a weak wind, that is, one of the authors (WADA) went out onto the snow surface through the doorways (No. 13 or 19 in the figure) and collected snow crystals on glass slides. The sampling time of snow crystals was between 1 and 10 s. After a certain amount of snow crystals were collected on the glass slide, the glass slide was placed in a petri dish which was covered with a lid to prevent the evaporation of snow crystals.

The snow crystals were quickly photographed using a stereoscopic microscope in a laboratory at about −25°C (No. 22 in the figure). As the temperature of the pathways between the doorways (No. 13 or 19) and the laboratory (No. 22) was between −10 and −20°C, it would be considered that snow crystals did not change their shapes.

Since the experimental apparatus and method were repeatedly described in other papers (KURODA and GONDA, 1984; GONDA *et al.*, 1984; GONDA and GOMI, 1985), further explanation is not given in this paper.

3. Results of Observation

Figure 2 shows the typical examples of hollow prisms, combination of bullets and single bullets observed at Mizuho Station under the air temperature of −25.8°C on March 20, 1979. As shown in Fig. 2b, the skeletal structures of a hollow prism considerably develope and it seems that the formation of deeply skeletal structures on the (0001) faces promotes further growth along *c*-axis of the crystal.

Figure 3 shows the number and percentage frequency of the different shapes of snow crystals observed at Mizuho Station on March 19, 1979. Air temperature during the observation was almost constant between −22.3 and −23.4°C. As shown in the figure, different shapes of snow crystals precipitated at the same time although air temperature was almost constant. These facts are also reported by KIKUCHI and HOGAN

Fig. 2. Typical examples of hollow prisms, combination of bullets and single bullets observed at Mizuho Station on March 20, 1979.

(1979) and KAJIKAWA *et al.* (1983). The formation frequency of hollow prisms and combination of plates is relatively high among different shapes of snow crystals. This fact means that the shapes of snow crystals growing at the temperature below −20°C are not determined by air temperature only.

Figure 4 shows the number and percentage frequency of the length along *c*-axis of the hollow prisms observed at Mizuho Station during March 1979 and January 1980. Air temperature during the whole periods when hollow prisms were observed ranged from −23 to −49.1°C. As shown in the figure, the hollow prisms of about 200 μm in length precipitated rather in excess. In the case of hollow prisms above 200 μm, the formation frequency of them is apt to decrease with increasing crystal size. The mean and maximum values of the length along *c*-axis of the hollow prisms observed are 293 and 630 μm, respectively.

Figure 5 shows the number and percentage frequency of the size ratio c/a of hollow prisms observed at Mizuho Station during March 1979 and January 1980. Air temperature is the same as that of Fig. 4. As shown in the figure, the hollow prisms with

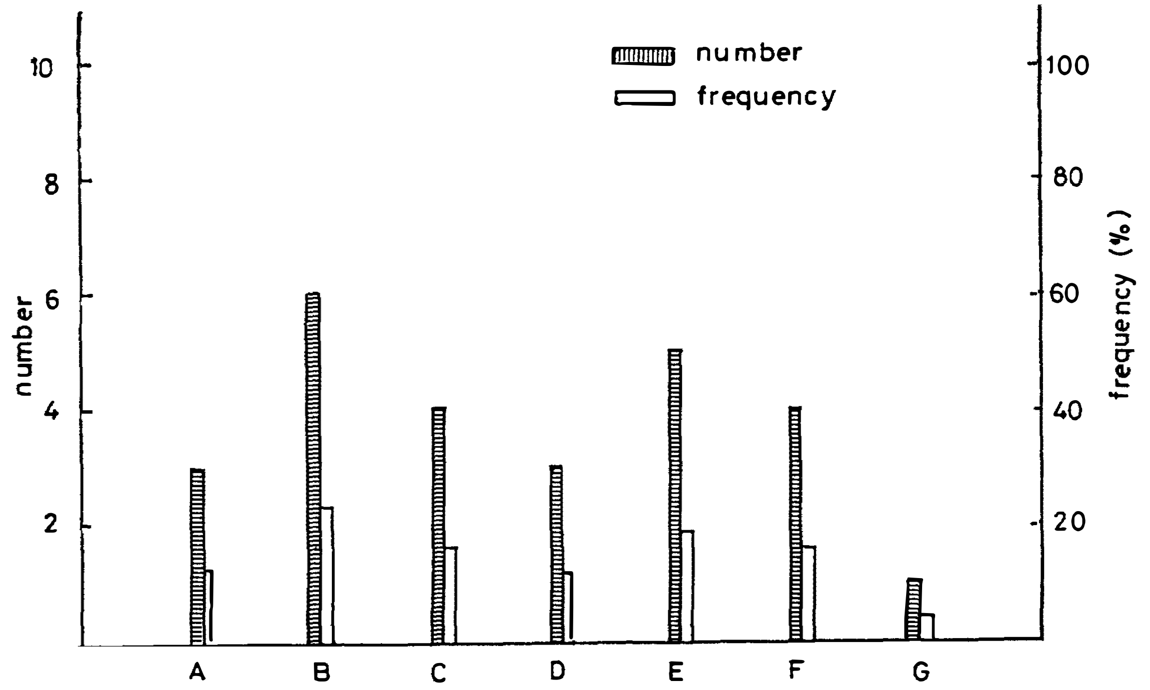

Fig. 3. Number and percentage frequency of the different shapes of snow crystals observed at Mizuho Station on March 19, 1979.
A: skeleton plate, B: hollow prism, C: combination of bullets, D: single bullet, E: combination of skeleton plates, F: combination of skeleton columns, G: combination of skeleton plates and skeleton columns.

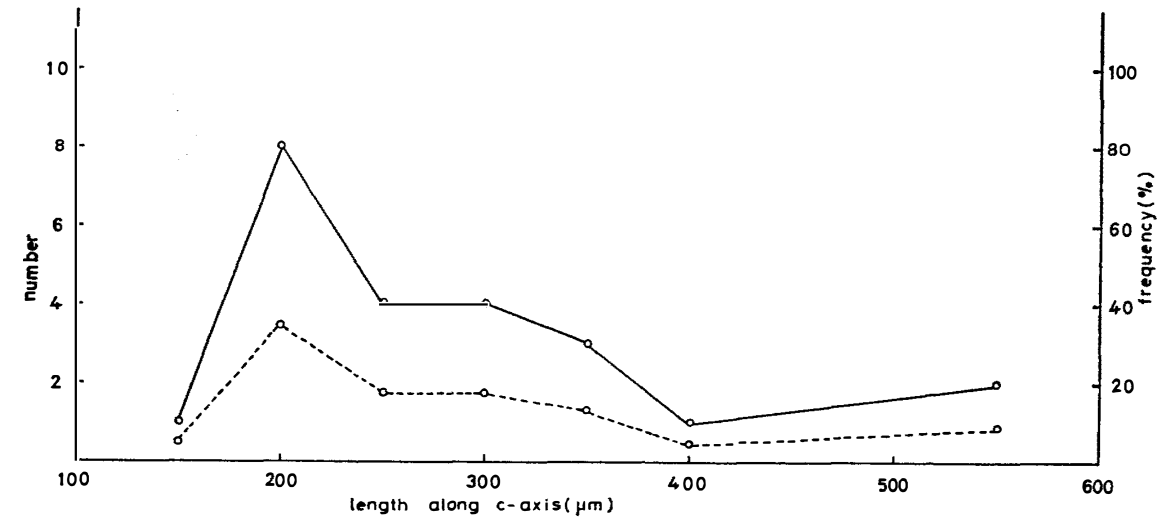

Fig. 4. Number (solid line) and percentage frequency (dotted line) of the length along c-axis of hollow prisms observed at Mizuho Station during March 1979 and January 1980.

the size ratio of about 3.0 precipitated with high frequency. In the case of the crystals with the size ratio c/a larger than 3.0, the formation frequency of them is apt to decrease with increasing size ratio c/a. The mean and maximum values of the size ratio of observed all hollow prisms are 3.6 and 6.1, respectively.

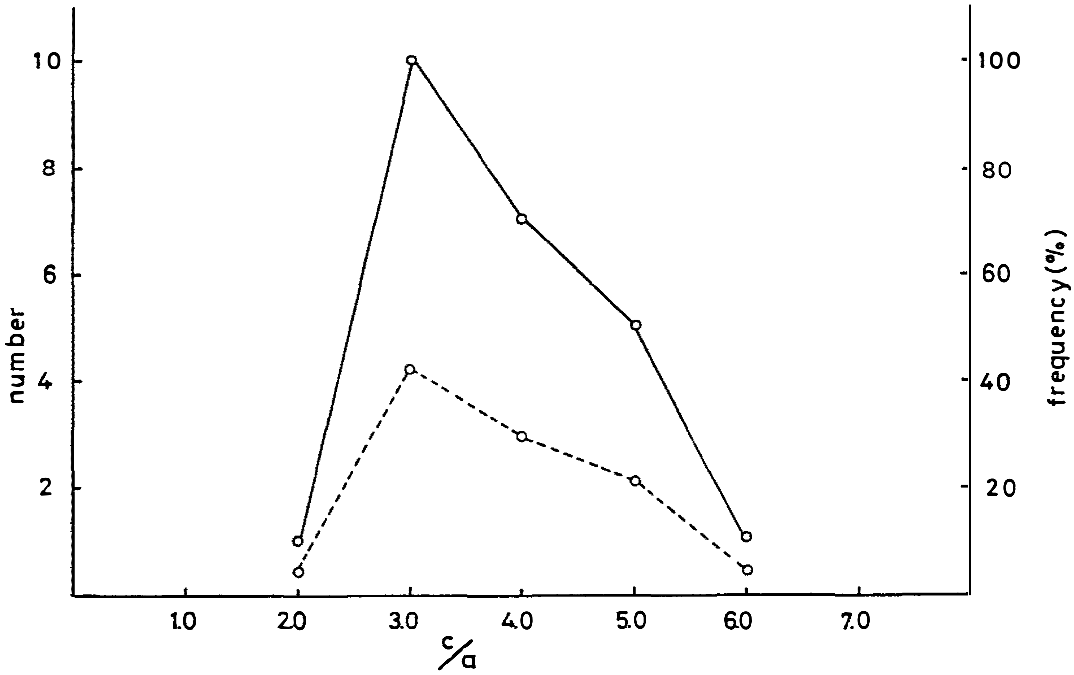

Fig. 5. Number (solid line) and percentage frequency (dotted line) of the size ratio c/a of hollow prisms observed at Mizuho Station during March 1979 and January 1980.

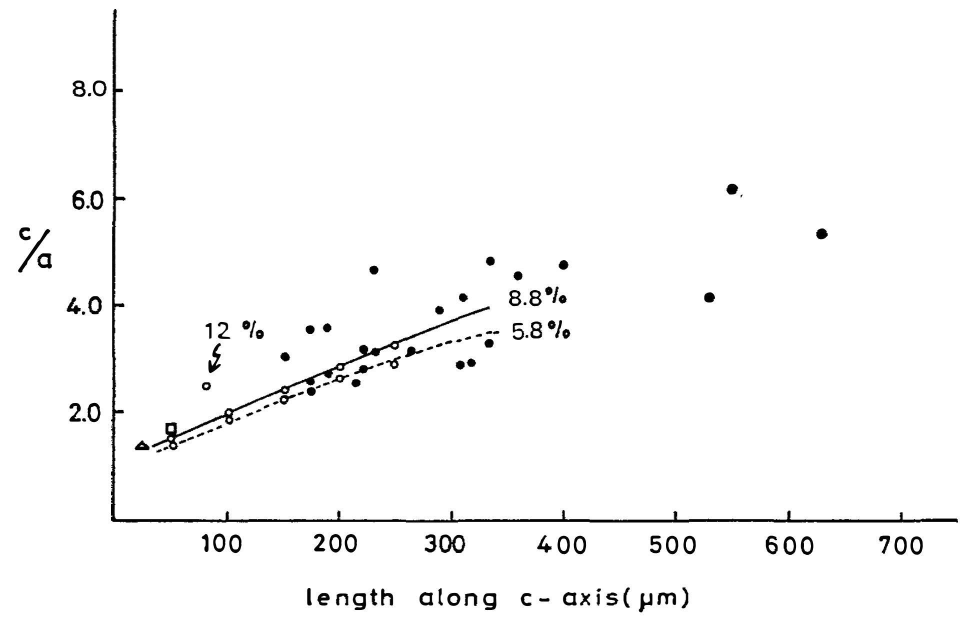

Fig. 6. The size ratio c/a of hollow prisms versus the length along c-axis of the crystals, which were observed at Mizuho Station during March 1979 and January 1980. Open circles show the experimental values of columnar ice crystals grown in air at 1.0 atm at −30°C and the supersaturation of 5.8, 8.8 and 12%. A triangle and a square show experimental values of columnar ice crystals grown in air of 1.0 atm at −7°C and a supersaturation of 7.1%, and at −50°C, respectively.

Figure 6 shows the size ratio c/a of hollow prisms versus the length along c-axis of the crystals. Open circles show the experimental values of columnar ice crystals grown in air at 1.0 atm at $-30°C$. A triangle and a square show experimental values of columnar ice crystals grown in air at 1.0 atm at -7 and $-50°C$, respectively. The size ratio c/a of the hollow prisms does not depend on the length along a-axis (not shown in the figure) but depends on the length along c-axis, that is, the size ratio c/a increases with increase of the length along c-axis. As described in the next section, by comparing observational values and experimental ones, it is estimated that the mean value in supersaturation during the whole periods when hollow prisms were observed is about 10%.

4. Discussion

The observations of snow crystals have been made at Mizuho Station, Antarctica during March 1979 and January 1980. It was found that different shapes of snow crystals precipitated at the same time under nearly constant air temperature at Mizuho Station. This fact means that the shapes of snow crystals growing below $-20°C$ are not determined by air temperature only.

It was also found that hollow prisms precipitated with considerable frequency together with various shapes of snow crystals. The hollow prisms with the size ratio c/a of about 3.0 were observed with relatively high frequency and the mean and maximum values of c/a of observed all hollow prisms are 3.6 and 6.1, respectively. The size ratio c/a of hollow prisms does not depend on the length along a-axis but depends on the length along c-axis; that is, the size ratio c/a increases with increase of the length along c-axis. As shown in Fig. 1, it is known that hollow prisms observed at Mizuho Station have large skeletal structures on the (0001) face of the crystals. By comparing the external form and the surface micromorphology of columnar ice crystals grown in a growth chamber with those of observed hollow prisms, it is inferred that the growth mechanism of observed hollow prisms is not a screw dislocation mechanism.

In Fig. 6, a triangle, open circles and a square show experimental values of columnar ice crystals grown in air of 1.0 atm at -7, -30 and $-50°C$, respectively. As shown in the figure, the crystal size dependences of the size ratios c/a of columnar ice crystals do not fluctuate markedly with temperature within the temperature range when hollow prisms were observed. Therefore, it will be permitted that we compare the observed values with the experimental ones of columnar ice crystals grown in air of 1.0 atm at $-30°C$. It is estimated from Fig. 6 that the mean value in supersaturation during the whole periods of observation is about 10%. It is reported that when ice crystals grow at 10% supersaturation or above, two-dimensional nuclei are formed at the corners of the crystals (GONDA *et al.*, 1985). Therefore, it is inferred from the external form of observed hollow prisms and their growth conditions that hollow prisms observed at Mizuho Station grew by a two-dimensional nucleation mechanism.

The reason why the size ratio c/a of hollow prisms does not depend on the length along a-axis but on the length along c-axis is that many water molecules preferentially accumulate onto the (0001) face of the crystals owing to the shape effect of diffusion field of water molecules around the crystals. The mean values of the air pressure and supersaturation during the whole periods of observation are about 0.72 atm and about 10%, respectively. As described above, this fact shows that the hollow prisms formed under this growth condition grow further in the direction of c-axis with increasing crystal size owing to the shape effect of diffusion field of water vapor.

5. Conclusions

Observations of snow crystals have been made using a stereoscopic microscope at Mizuho Station, Antarctica during March 1979 and January 1980. Observational results obtained are as follows:

1) Different shapes of snow crystals precipitate at the same time under nearly constant air temperature below $-20°C$; so the shapes of snow crystals growing below $-20°C$ are not determined by air temperature only.

2) Hollow prisms precipitate with considerable frequency together with different shapes of snow crystals.

3) The mean values of the crystal size and the size ratio c/a of the hollow prisms are 293 μm and 3.6, respectively.

4) The size ratio c/a of the hollow prisms does not depend on the length along a-axis but depends only on the length along c-axis; and the size ratio c/a increases with increase of the length along c-axis.

5) By comparing the observational values with the experimental ones, it is estimated that the mean value in supersaturation during the whole periods when hollow prisms were observed is about 10%.

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