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MORPHOLOGICAL FEATURES OF COMBINATION OF BULLET-TYPE SNOW CRYSTALS OBSERVED AT SYOWA STATION, ANTARCTICA

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Abstract: Morphological features of combination of bullet-type snow crystals replicated at Syowa Station, Antarctica are discussed from observations using a stereomicroscope. Some stereophotomicrographs of them are shown.

The number of bullets forming the combination was counted. The bullets with five components were the most frequently observed. The maximum number of components was ten.

The angles of their *c*-axes were measured, and found that about 70°, 55° and 88° or their supplementary angle were predominant. In addition, 64° and 78° were found. These angles may be explained by the CSL theory by T. KOBAYASHI *et al.* (J. Cryst. Growth, **32**, 233, 1976).

Apparent pyramidal faces of bullet crystals are not the crystallographic pyramidal faces; $\{10\bar{1}1\}$, but are mere skeleton structures. These findings will be important for discussing the optical phenomena in the Antarctic atmosphere.

1. Introduction

It is well known that ice crystals or snow crystals formed at low temperature, such as in the Antarctic atmosphere and in cirrus or cirrostratus clouds, are mainly of bullet and columnar types (KIKUCHI and YANAI, 1971; HEYMSFIELD and KNOLLENBERG, 1972).

Size distribution of bullet crystals was investigated by KIKUCHI (1968). The angles of the *c*-axes of bullet crystals were measured by KOBAYASHI *et al.* (1976). UYEDA and KIKUCHI (1979) studied the three-dimensional configuration of combination of bullet-type snow crystals.

Up to the present, however, few studies have been made on morphological features of snow crystals of bullet type, because such crystals have been scarcely observed in the temperate region.

In this paper, morphological features of combination of bullet-type snow crystals are discussed from observations using their stereomicrographs.

2. Method of Observation

Replicas of snow crystals are made with one per cent polyvinyl formal in ethylene dichloride. The number of crystals forming the combination is counted under a stereomicroscope. The angles of their *c*-axes were measured from their photomicrographs taken by placing the *c*-axes on the horizontal plane using a simple universal stage.

Morphological features are examined by taking the stereophotomicrographs with the method described by IWAI (1981, 1983).

Replicas of the combination of bullets described in this paper were made on 19, 20 August and 1 September 1977 at Syowa Station, Antarctica. The replicas are not considered to be deformed.

3. Meteorological Conditions

Figure 1 shows a time-height cross section of temperature and relative humidity during 19 to 20 August 1977 at Syowa Station. Observation period is shown by solid lines in the figure.

Surface inversion layer exists while the bullet crystals fall. We can see the layer of about $-16°C$ between 900 and 970 mb. The layer higher than 75% in relative humidity with respect to water exists below 700 mb level, and its temperature range is $-28°$ to $-16°C$. Plate-like snow crystals can grow at $-16°C$. Indeed, snow crystals fallen in this period are bullets with plates.

Figure 2 shows a time-height cross section of temperature and relative humidity during 1 to 2 September 1977 at Syowa Station.

Combination of bullet-type snow crystals begin to fall when cold air enters above 800 mb level. The layer higher than 70% in relative humidity is isothermal of $-27°$ to $-29°C$. In this case, almost all the snow crystals were combined bullets. A few of them consisted of combination of bullets and crossed plates.

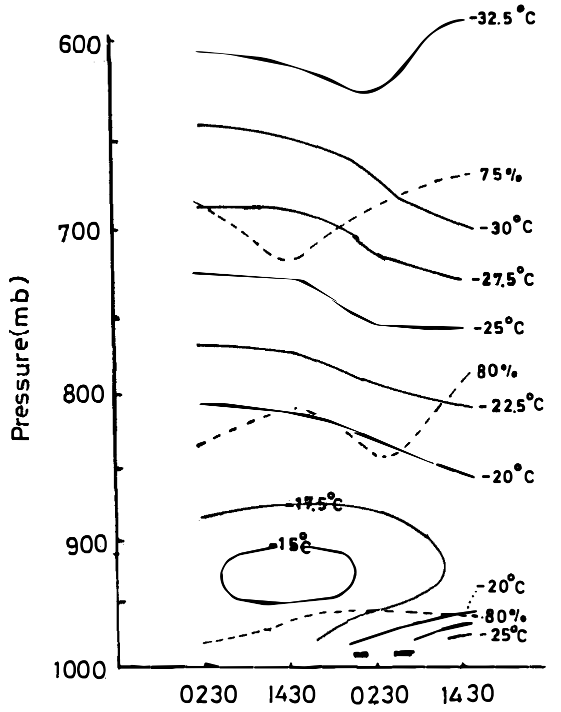

Fig. 1. Time-height cross section of temperature and relative humidity with respect to water during 19 to 20 August 1977 at Syowa Station. Observation time is shown by solid lines in the figure below.

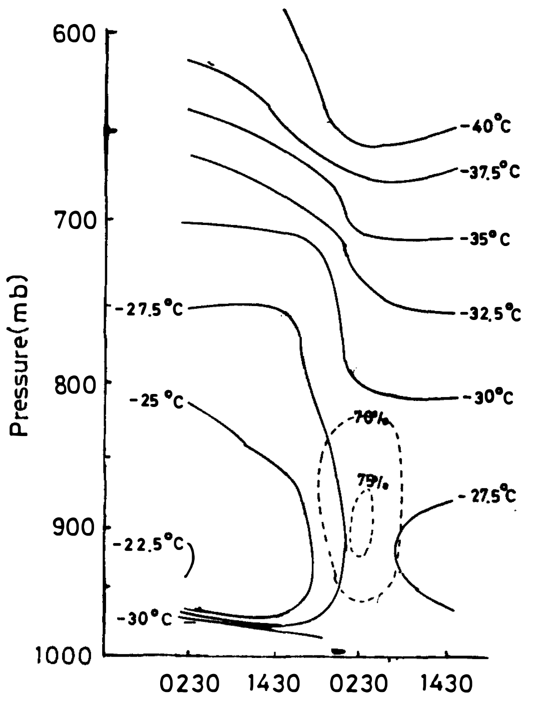

Fig. 2. Time-height cross section of temperature and relative humidity with respect to water during 1 to 2 September 1977 at Syowa Station.

4. Results and Discussions

4.1. Morphological features of the combination of the bullet-type crystals

Figure 3 shows two single bullets. Pyramidal faces seem to appear at an end of columner crystal shown by solid lines. However, these are not the crystallographic pyramidal faces, $\{10\bar{1}1\}$, but mere skeleton structures. The reason why the skeleton structures appeared at one end of the columnar crystal may be due to the formation of single bullet crystals. The formation of single bullet crystals is discussed later.

Figure 4 shows a stereophotomicrograph of a single bullet crystal taken along the *c*-axis. From the stereophotomicrograph, we can immediately understand that apparent pyramidal faces are not the crystallographic faces but are mere skeleton structures. This finding will be important for explaning halos in Antarctica.

A halo with an angular radius of about 8° is observed in Antarctica (HUMPHREYS, 1964). It is attributed to the ray path from the pyramidal face to the prism face (WALLACE and HOBBS, 1977). In general, however, a halo with an angular radius of about 8° is rarely observed in Antarctica. From this, the crystallographic pyramidal face rarely appears in the case of bullet-type crystals even though they are commonly observed in Antarctica.

It, however, does not deny that the crystallographic pyramidal faces appear during the growth of ice crystal. KOBAYASHI (1965) has shown that the pyramidal face appears at the end of columnar ice crystals grown from the vapor phase below $-50°C$.

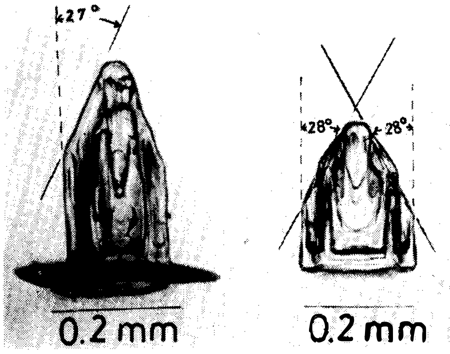

Fig. 3. An example of two bullet-type crystals which would seem to appear the pyramidal face.

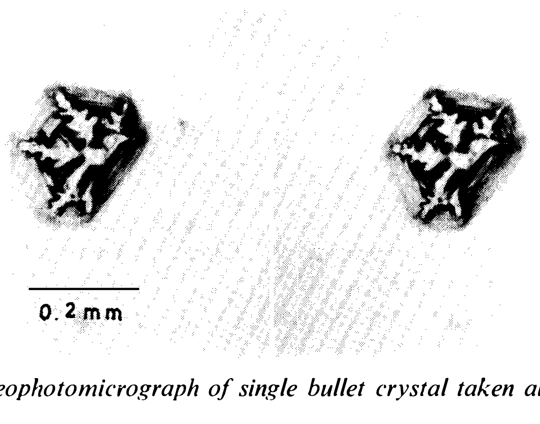

Fig. 4. A stereophotomicrograph of single bullet crystal taken along the c-axis.

Figure 5 shows the crystal which consists of seven bullets and one crossed plate. The shape of a columnar part of a bullet shown by A is triangle. Crystal B is a crossed plate. Figure 6 shows a stereophotomicrograph of the snow crystal which consists of five bullets and two crossed plates. The angle of the c-axes of four bullets is 33°.

Capped bullets as shown in Fig. 3 can be explained as follows: Bullet-type crystals grow below $-20°C$; thereafter, plates grow at the end of the columnar part of bullet crystals at $-16°C$. However, the crystal shown in Fig. 6 cannot be explained by the same way mentioned above, because bullets and plates seem to grow simultaneously. We can find the similar crystals in the paper of MAGONO and LEE (1966). These crystals will present a problem from a viewpoint of the habit, because plate-like crystals and columnar-like crystals seem to grow simultaneously.

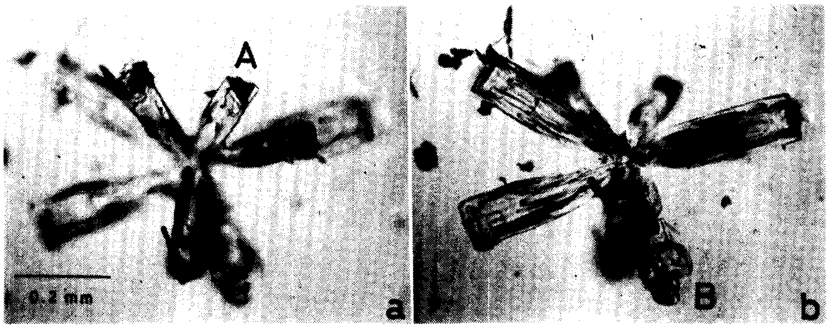

Fig. 5. An example of trigonal shaped bullet (shown by A). a: upper focussing, b: lower focussing.

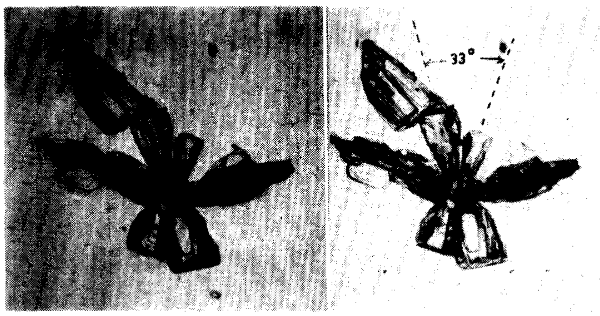

Fig. 6. A stereophotomicrograph of combination of bullets and crossed plates.

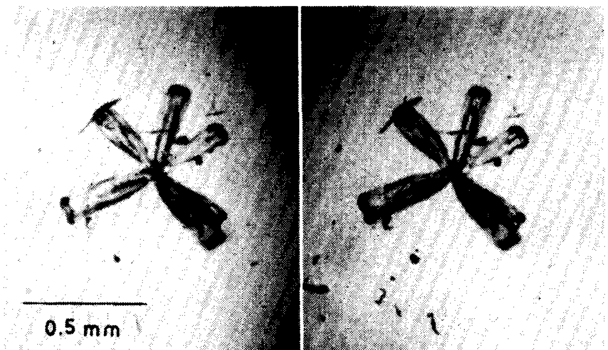

Fig. 7. A stereophotomicrograph of combination of bullets having six components.

Figures 7–10 show the typical examples of bullet crystals having more than six components. Figure 7 shows a stereophotomicrograph of the snow crystal consisting of six bullets. Five bullets of them are almost in the same plane. The angle of the *c*-axes of the penetrated four bullets is 70° or 110°.

Figure 8 also shows a stereophotomicrograph of a combination of bullet having six components. Four of them seem to penetrate each other.

Figure 9 shows a stereophotomicrograph of a combination of capped bullet having eight components.

Figure 10 shows a stereophotomicrograph of the snow crystal consisting of ten bullets. This combination of bullet crystal had the maximum number of components in the present observations.

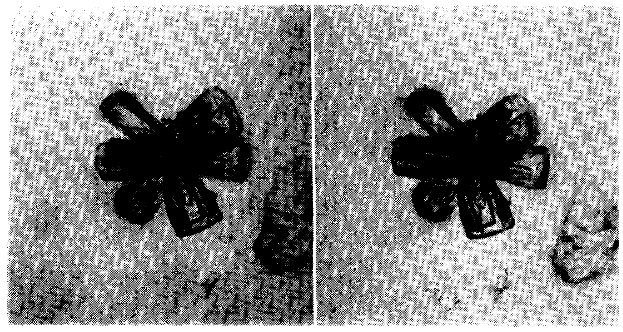

Fig. 8. A stereophotomicrograph of combination of bullets having six components.

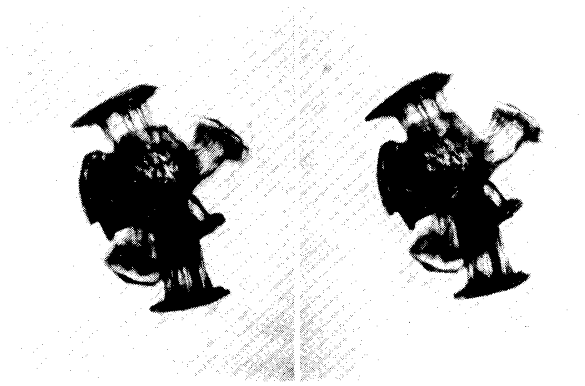

Fig. 9. A stereophotomicrograph of combination of bullets having eight components.

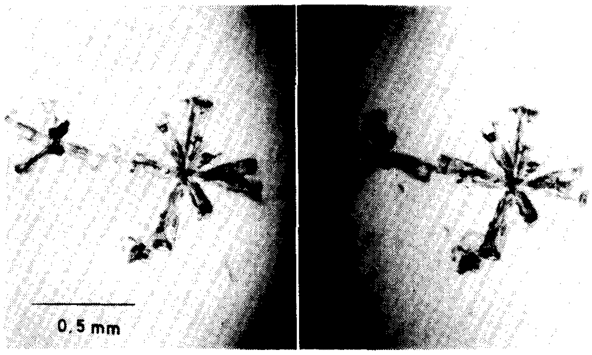

Fig. 10. A stereophotomicrograph of combination of bullets having ten components.

4.2. Number of components of the combination of the bullet-type crystals

Figure 11 shows the frequency distributions of the number of components forming the combination of bullet-type crystals. Solid and broken lines show the case on 19 August and 1 September 1977, respectively. In both cases, five was the maximum components. The percentage of single bullets fallen on 19 August is larger than that on 1 September. On the other hand, the percentage consisting of more than five components fallen on 19 August is smaller than that on 1 September.

These distributions are considerably different from that observed by KIKUCHI (1968) in Hokkaido. His results show that single bullets were the most frequently observed and the percentage decreases with increasing number of components. From the size distribution, he concludes that single bullet crystals are produced by the disintegration of the combination of bullets during their descent.

From the comparison between the case on 19 August and that on 1 September, it seems that single bullets are produced by the disintegration of combination of bullets consisting of more than five components.

As shown in Figs. 5–10, bullet crystals always combine at the cone of each bullet crystal. Figure 12 shows the single bullet having a broken piece at the end of the pyramid shown by A. This broken piece may be a torn-off part of another bullet crystal. Combination of bullet crystals is made artificially but single bullet crystals are not freely made artificially. The author agrees with the opinion of KIKUCHI (1968) on the formation of single bullets mentioned above.

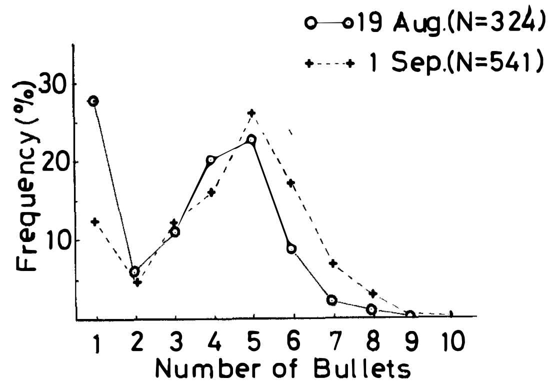

Fig. 11. Frequency distributions of the number of component of each combination of bullet-type snow crystal. N is the total number of each combination of bullet crystal.

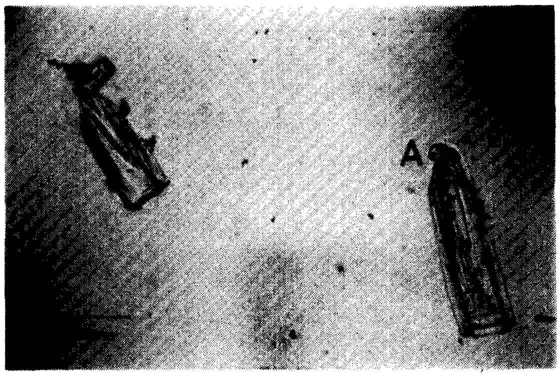

Fig. 12. An example of single bullet having a piece at the end of pyramid.

4.3. The angle of the c-axes of combined bullets

Figure 13 shows examples of the combination of 4 or 5 bullets. These crystals seem to penetrate each other. The axial angles of a, b, c and d are 55°, 64°, 70° and 78°, respectively. According to the CSL theory of twin crystal proposed by KOBAYASHI *et al.* (1976), these angles may be explained by the twin crystals composed of {10$\bar{1}$1}, {10$\bar{1}$3}, {30$\bar{3}$8} and {30$\bar{3}$7} planes. However, some questions will remain, because these crystals are not considered as penetration twins except {30$\bar{3}$8} relation. The {30$\bar{3}$8} penetration twin was discussed by the author (1971).

Figure 14 shows the peculiar snow crystal which is very similar to that found by KIKUCHI (1969) at Syowa Station, Antarctica. This peculiar crystal has a bullet, and the angle between the *c*-axis is 78°. These are explained by {30$\bar{3}$7} relation of the twin crystal mentioned above.

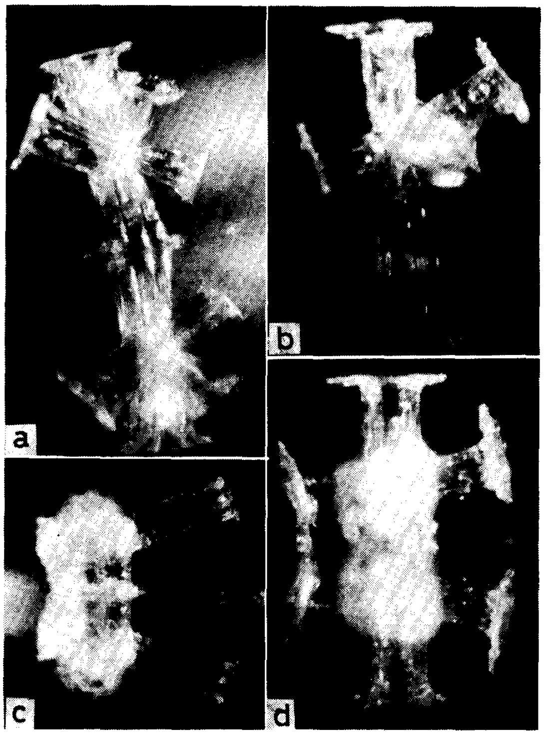

Fig. 13. Examples of combination of bullets whose axial angle is different each other. a: 55°, b: 64°, c: 70° (110°), d: 78°. Lower figures of each crystal show the reflection one by a glass slide.

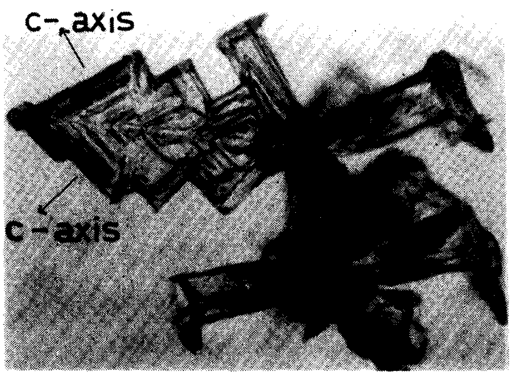

Fig. 14. A peculiar snow crystal with bullet. Axial angle is 78° (102°).

Other stereophotomicrographs of bullet-type crystals will be published in the Journal of the Faculty of Education, Shinshu University in the near future.

5. Conclusions

Morphological features of combination of bullet-type snow crystals replicated at Syowa Station are discussed from observations using a stereomicroscope and stereophotomicrographs.

The results are as follows:

(1) Snow crystals of combination of bullet-type having five components were most frequently observed.

(2) The maximum number of components was ten.

(3) The angles of their *c*-axes were predominantly 70°, 55° and 88° or the supplementary angle.

(4) Apparent pyramidal faces of bullet-type crystals are not the crystallographic pyramidal faces, $\{10\bar{1}1\}$, but are mere skeleton structures.

(5) The peculiar snow crystal with bullets, very similar to the one observed by KIKUCHI (1969) at Syowa Station, was found.

Acknowledgments

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