[Journal of the Faculty of Science, Hokkaido University, Ser. VII (Geophysics), Vol. V, No. 2, 1977]

The Internal Structure and Embryo of Graupel

Toshio HARIMAYA

(Received Dec. 28, 1977)

Abstract

Observations of graupel particles were carried out by the thin section method with special attention on the embryo position in a graupel particle and the internal structure of graupel particles. Graupel particles with the section of a snow crystal or branches on top were found. Then, it was reconfirmed that snow crystals can become the embryo of graupel particles.

The size of crystals within graupel particles are dependent on the environmental temperature where graupel particles grow. The formation mechanism of graupel particles considered in a previous paper[1] were reconfirmed from the crystal structure of graupel particles.

1. Introduction

A method of hail suppression was based on the following idea. If the number density of hail embryos increases in a cloud, the available liquid water content for a hail embryo decreases. Accordingly large hailstones are not formed. In most cases the hail embryo is graupel[2),3),4)]. Hence, studies of the generation and growth of graupel are important in the elucidation of hail suppression. Likewise in a discussion of graupel generation, knowledge regarding graupel embryos is required.

It is considered that the internal structures of graupel particles are dependent on environmental temperature, the impact velocity of cloud droplets, liquid water content, the size distribution of cloud droplets and so on. By a simultaneous study of the internal structure of graupel particles and meteorological conditions, contributing factors to the internal structure can be found. Previously, contributing factors to the crystal size, crystallographic orientation and bubble structure of rimes were clarified by riming experiments[5),6)]. Accordingly, the observational results regarding the contributing factors for the internal structure of graupel particles can be verified by the results of the riming experiments.

Observational results of graupel embryos were presented in a previous paper[1)], in which the graupel particles were observed by the thin section method and direct method in which the graupel particles are picked apart under a microscope. The results showed that both snow crystals and frozen drops can become graupel embryos. We have continued our observations by thin section method, with special attention on the embryo position in a graupel particle and also on the internal structure of graupel particles. The observational results regarding the embryo and internal structure of graupel will be described in this paper. In addition, the formation mechanism of graupel will be considered, based on the results mentioned above.

2. Embryo

Graupel particles were classified into hexagonal graupel, conelike graupel and lump graupel by Nakaya[7]. The formation mechanism for these three kinds of graupel particles were presented by Harimaya[1] by combining information of the embryo and falling behavior of graupel, which are shown in Fig. 1.

Plane snow crystals usually fall with their a-axes held horizontally, thus accreting cloud droplets on the under side. Accordingly it is considered that it will grow to conelike graupel a_3 through hexagonal graupel a_2 when it continues to fall through a cloud keeping a constant attitude. If a thin section in parallel to its growth direction through its center is made, it may expected that it would have a section of a snow crystal on top as the embryo.

The thin sections of graupel particles are shown by polarization microscope photographs as follows. This optical system can easily detect the c-axis of thin sections under a sensitive color plate, that is to say, when the color is yellow the c-axis is directed from top to bottom and when the color is blue the c-axis is directed from right to left.

Photo. 1 shows a thin section of a graupel particle with a section of a snow crystal on top. The yellow straight line at the top is the section of a snow crystal. The color is yellow, hence its c-axis is directed from top to bottom. Accordingly the straight line is considered to be the section of a plane snow crystal.

Photo. 2 shows a graupel particle with sections of branches of a snow crystal on top. The yellow portions are the sections of branches of a snow crystal. The colors are yellow, hence their c-axes are directed from top to bottom. Accordingly the portions are considered to be the sections of branches of a plane snow crystal.

Photo. 3 also shows a thin section of a graupel particle. No traces of a

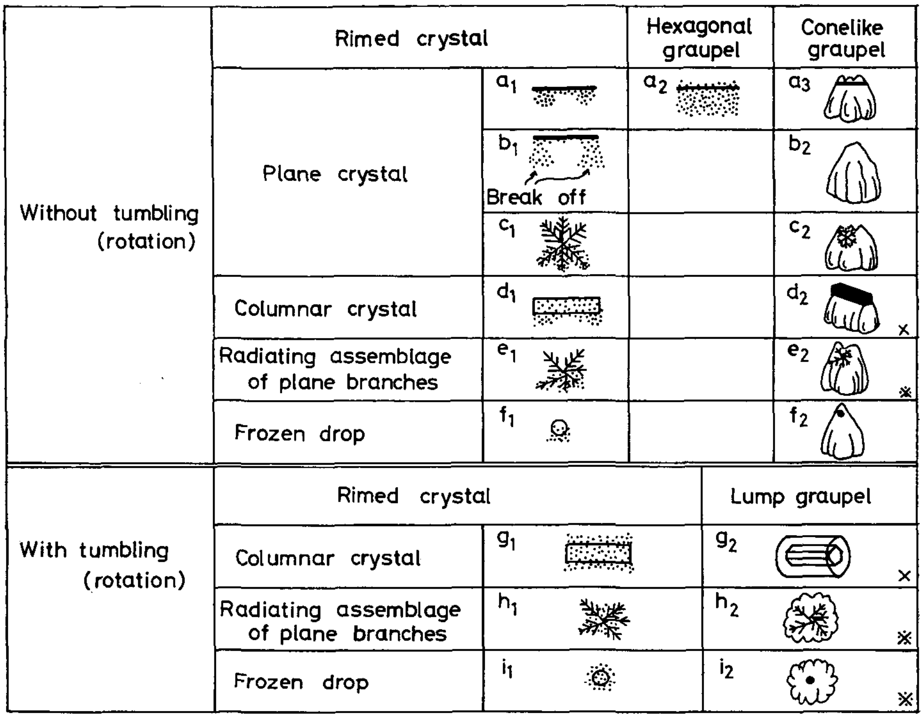

Fig. 1 Formation mechanism of three kinds of graupel particles. Graupel particles of type suffixed by x-marks at the right end have not yet been found, although expected. Graupel particles of type suffixed by ※-marks have been found, but their embryos have not yet been detected.

snow crystal were found on top of the graupel particle, but it appears that each component crystal with the same crystallographic orientation grew from the straight line drawn on the top of the graupel particle. According to observations by the thin section method the graupel particles with traces of snow crystals were limited, but numerous graupel particles without traces of snow crystals were seen as shown in Photo. 3. This may be explained by the transformation of snow crystals. Because several hours had elapsed from the growth of graupel to polarization microscope observation. In addition, the observed graupel may have contained graupel indicated by b_2 in Fig. 1.

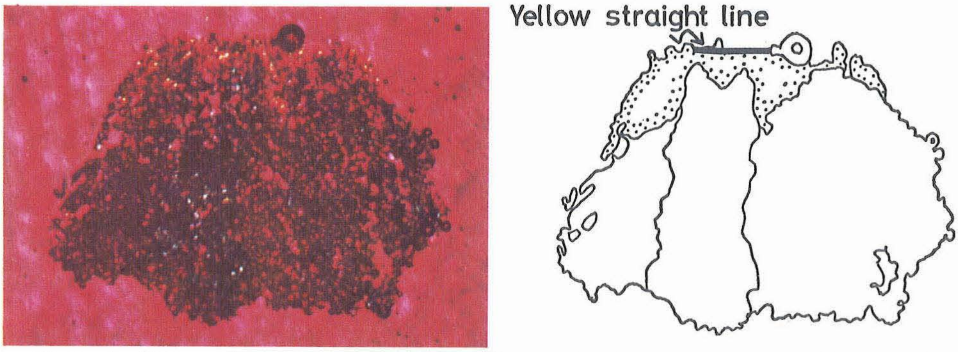

Photo. 1 Thin section of a graupel particle with section of a snow crystal on top. Yellow straight line is the section of a snow crystal. (×16)

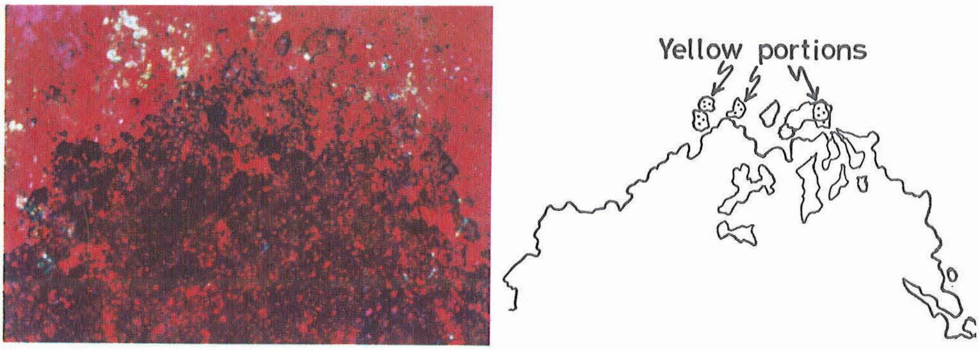

Photo. 2. Thin section of a graupel particle with sections of branches of a snow crystal on top. Yellow portions show the sections of branches of a snow crystal. (×16)

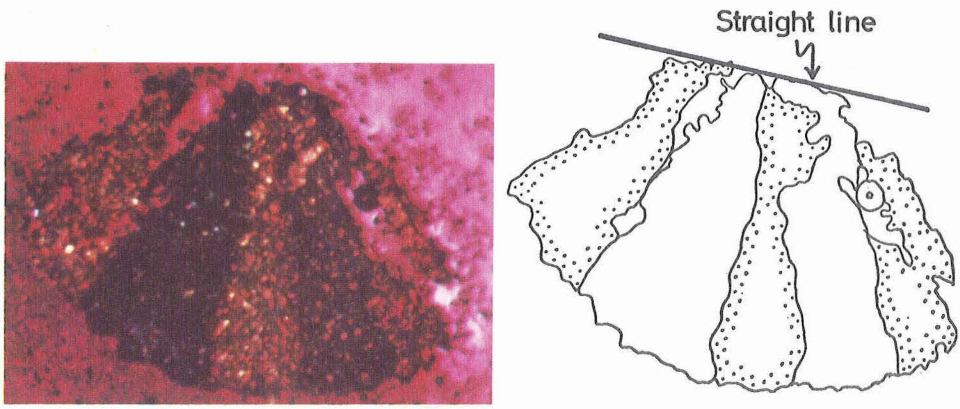

Photo. 3. Thin section of a graupel particle with each component crystal growing from the straight line drawn at the top. (×16)

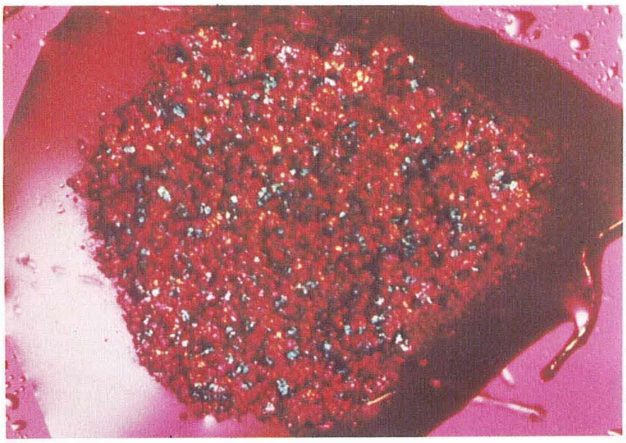

Photo. 4. Thin section of a graupel particle composed of small crystals. ($\times 16$)

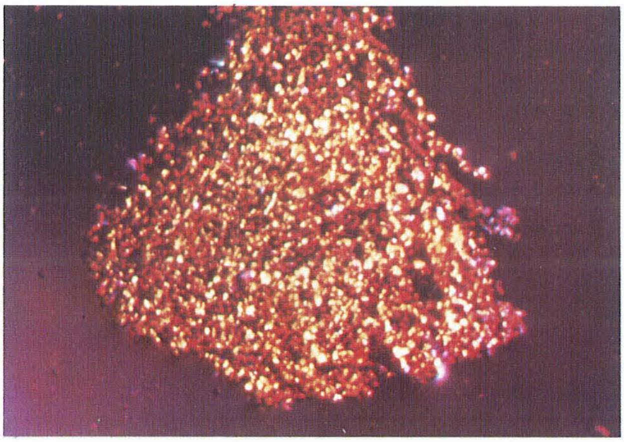

Photo. 5 Conelike graupel seen as a uniform yellow under a polarization microscope. ($\times 16$)

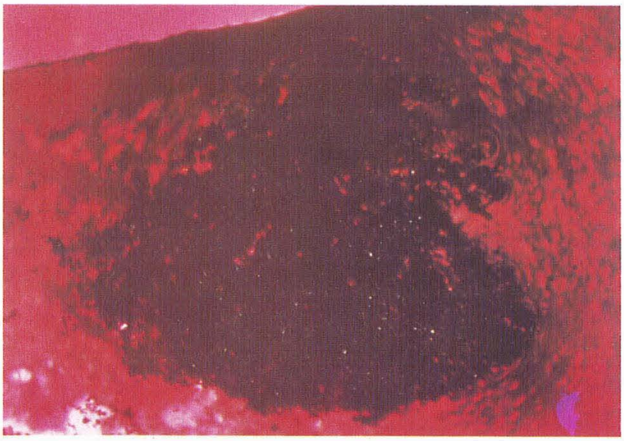

Photo. 6 Conelike graupel seen as a uniform blue under a polarization microscope. ($\times 16$)

3. Internal structure

List[8]), and Takahashi and Magono[9]) observed thin sections of graupel particles under a polarization microscope and reported that graupel particles grow by riming.

In the present observation many thin sections were made in an attempt to study the characteristics of the internal structure of graupel particles. At first the size of the component with the same crystallographic orientation (hereinafter crystals) was studied. The thin section of graupel particles were composed of large crystals as shown in Photos. 1 and 3. The reference to large crystals here actually are of a crystal size of about few milimeters. In contract the small crystals are about 100 μm as shown in Photo. 4. The difference between the large crystals and the small crystal is clear as seen in Photos. 3 and 4. But graupel particles of medium crystal size are found at times.

The graupel particles which fall simultaneously are composed of crystals of the same size, thus it was considered that crystal sizes reflect meteorological conditions. Next the relation between crystal size and environmental temperature was studied. Fig. 2 shows the vertical distributions of temperature below the cloud top. Solid lines show the sounding curves when graupel particles composed of large crystals fell, broken lines indicate small crystals and dotted lines indicate medium crystals, respectively. The heights

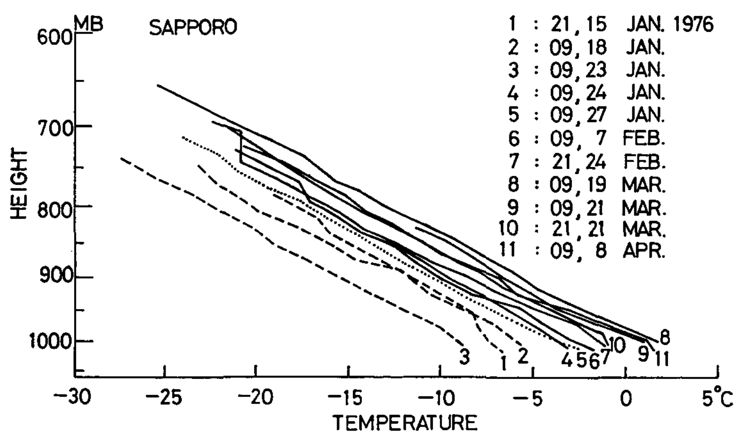

Fig. 2 Vertical distributions of temperature below cloud tops. Solid lines show the sounding curves corresponding to large crystals, broken lines to small crystals and dotted lines to medium crystals, respectively.

of cloud tops were determined from the vertical distributions of temperature and humidity. It is seen in Fig. 2 that graupel particles are composed of large crystals when the temperatures in clouds are warm and are composed of small crystals when the temperature is cold. Regarding this Brownscombe and Hallett[5] reported as a result of their riming experiment with cloud droplets with a radii of 20 μm that the rime was composed of large crystals in the case when the environmental temperature was warmer than −14°C and that the rime was composed of small crystals in the case when the environmental temperature was colder than −14°C. The position in a cloud where graupel particles grew could not be determined exactly in the present observation. Accordingly the threshold temperature from large crystals to small crystals could not be determined. But the present observational results are in agreement with Brownscombe and Hallett's experimental results qualitatively.

4. Consideration

In a previous paper[1] the formation mechanisms were considered by combining information of the embryo and falling behavior of graupel. In the present paper the formation mechanisms were discussed by combining information of the embryo and falling behavior, to which was added the relation between environmental temperature and crystal size.

In riming experiments of supercooled droplets on the surface of an ice plate of single crystals, Magono and Aburakawa[10] reported that the droplets were frozen into single crystals with the same crystallographic orientation as the ice plate at temperature regions warmer than −5°C, while the droplets were frozen into poly crystals or single crystals with the crystallographic orientation different from the ice plate in temperature regions colder than −15°C. Based on these experimental results, the frozen cloud droplets would have the same crystallographic orientation as the basal plane when cloud droplets accrete plane snow crystals in warm temperature regions in the clouds. Then, if cloud droplets continue to accrete the snow crystal in a warm temperature region in the cloud, the c-axis direction of the resulting conelike graupel particle is vertical in the case of falling behavior as shown by a_1, a_2 and a_3 in Fig. 1. Because the frozen cloud droplets have the same crystallographic orientation as the snow crystal in warm temperature regions. Accordingly the color of the conelike graupel can be seen as a uniform yellow under this polarization microscope system. An example is shown in Photo. 5. The c-axis direction of the resulting conelike graupel particle is horizontal

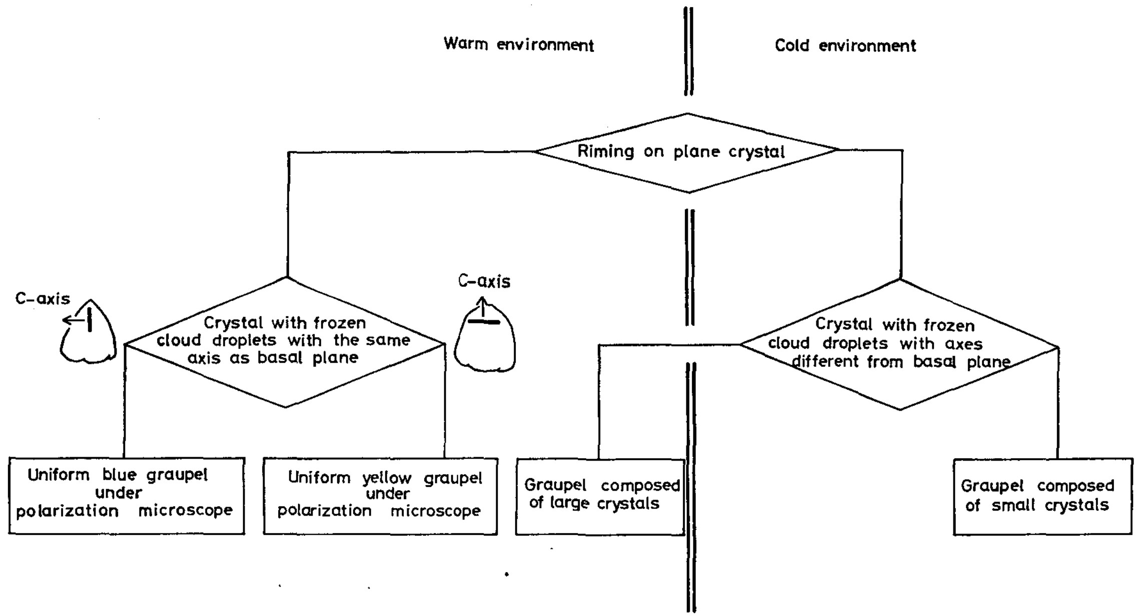

Fig. 3 Graupel particles growing from plane snow crystals.

in the case of the falling behavior shown by c_1 and c_2 in Fig. 1. Accordingly the color of the conelike graupel can be seen as a uniform blue under this polarization microscope system. An example is shown in Photo. 6. The growth processes from a_1 to a_3 through a_2 and from c_1 to c_2 as shown in Fig. 1 presented by combining information of the embryo and the falling behavior are reconfirmed by the study of crystal structure as mentioned above.

The frozen cloud droplets have crystallographic orientations different from the basal plane when cloud droplets accrete plane snow crystals in cold temperature regions in the clouds. The resulting graupel particle would be composed of several large crystals, then, if the snow crystal falls through a warm temperature region in the cloud and continues to accrete cloud droplets. Because the later rimes have the same crystallographic orientation as the former rimes which are poly crystals. The examples are shown in Photos. 1 and 3.

If the snow crystal with frozen droplets with crystallographic orientation different from its basal plane continues to fall through a cold region of the cloud, the resulting graupel particle would be composed of small crystals. An example is shown in Photo. 4. The considerations mentioned above are summarized in Fig. 3.

5. Conclusion

Observations regarding graupel particles were carried out with special attention to the embryo position in a graupel particle and the internal structure of graupel particles. The embryos were studied from view points of shape and the crystallographic orientation. As a result, graupel particles with the section of a snow crystal or branches on top were found by the thin section method. Graupel particles with component crystals growing from the straight line drawn at the top were also found. And it was assumed that a snow crystal was present at the straight line. Thus it was reconfirmed from these observational results that snow crystals can become the embryo of graupel particles.

The size of crystals within graupel particles are dependent on the environmental temperature. That is to say, large crystals are formed when the temperatures in the clouds are warm and vice versa. This result agrees with the riming experimental results of other workers.

In a previous paper[1] the formation mechanisms of graupel particles were considered by combining information of the embryo and falling behavior of graupel. Among these, the formation mechanism of graupel particles growing from plane snow crystal was reconfirmed from the crystal structure in present paper.

Acknowledgements: The author wishes to express his hearty thanks to Prof. C. Magono for his encouragement and discussion throughout this study.

The expense of this work was defrayed by a scientific research fund from the Education Ministry of Japan.

References

1) HARIMAYA, T.: The embryo and formation of graupel. J. Meteor. Soc. Japan, **54**, (1976) 42–51.
2) LIST, R.: Kennzeichen atmosphärischen Eispartikeln, 2. Teil. Hagelkörner. Z. Angew. Math. Phys., **9A**, (1958) 217–234.
3) LIST, R.: Growth and structure of graupel and hailstones. Monogr. No. **5**, Amer. Geophys. Union, Physics of precipitation, (1960) 317–324.
4) KNIGHT, C.A. and N.C. KNIGHT: Hailstone embryos. J. Atmos. Sci., **27**, (1970) 659–666.
5) BROWNSCOMBE, J.L. and J. HALLETT: Experimental and field studies of precipitation particles formed by the freezing of supercooled water. Quart. J. Roy. Meteor. Soc., **93**, (1967) 455–473.
6) LEVI, L. and A.N. AUFDERMAUR: Crystallographic orientation and crystal size in cyclindrical accretions of ice. J. Atmos. Sci., **27**, (1970) 443–452.
7) NAKAYA, U.: Snow Crystals, natural and artificial. Harvard Univ. Press, (1954).
8) LIST, R.: Kennzeichen atmosphärischer Eispartikeln, 1. Teil. Graupeln als Wachstumszentren von Hagelkörnern. A. Angew. Math. Phys., **9A**, (1958) 180–192.
9) TAKAHASHI, T. and C. MAGONO: Crystalline structure of hail and rime. (in Japanese). Tenki, **8**, (1961) 154–155.
10) MAGONO, C. and H. ABURAKAWA: Experimental studies on snow crystals of plane type with spatial branches. J. Fac. Sci., Hokkaido Univ., Ser. VII, **3**, (1968) 85–97.