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Rime and Graupel: Description and Characterization as Revealed by Low-Temperature Scanning Electron Microscopy

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Summary: Snow crystals, which form by vapor deposition, occasionally come in contact with supercooled cloud droplets during their formation and descent. When this occurs, the droplets adhere and freeze to the snow crystals in a process known as accretion. During the early stages of accretion, discrete snow crystals exhibiting frozen cloud droplets are referred to as rime. If this process continues, the snow crystal may become completely engulfed in frozen cloud droplets. The resulting particle is known as graupel. Light microscopic investigations have studied rime and graupel for nearly 100 years. However, the limiting resolution and depth of field associated with the light microscope have prevented detailed descriptions of the microscopic cloud droplets and the three-dimensional topography of the rime and graupel particles. This study uses low-temperature scanning electron microscopy to characterize the frozen precipitates that are commonly known as rime and graupel. Rime, consisting of frozen cloud droplets, is observed on all types of snow crystals including needles, columns, plates, and dendrites. The droplets, which vary in size from 10 to 100 µm, frequently accumulate along one face of a single snow crystal, but are found more randomly distributed on aggregations consisting of two or more snow crystals (snowflakes). The early stages of riming are characterized by the presence of frozen cloud droplets that appear as a layer of flattened hemispheres on the surface of the snow crystal. As this process continues, the cloud droplets appear more sinuous and elongate as they contact and freeze to the rimed crystals. The advanced stages of this process result in graupel, a particle 1 to 3 mm across, composed of hundreds of frozen cloud droplets interspersed with considerable air spaces; the original snow crystal is no longer discernible. This study increases our knowledge about the process and characteristics of riming and suggests that the initial appearance of the flattened hemispheres may result from impact of the leading face of the snow crystal with cloud droplets. The elongated and sinuous configurations of frozen cloud droplets that are encountered on the more advanced stages suggest that aerodynamic forces propel cloud droplets to the trailing face of the descending crystal where they make contact and freeze.

Key words: field-emission scanning electron microscopy, low-temperature scanning electron microscopy, snow crystals, snowflakes, rime, graupel

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Introduction

For more than 100 years, scientists have observed and photographed numerous types of precipitating snow crystals with the light microscope (LM) (Bentley and Humphreys 1931, Magono and Lee 1966, Nakaya 1954). To help characterize the basic shapes and to standardize the crystal terminology, various classification schemes were proposed (Bentley and Humphreys 1931, Hellman 1893, Magono and Lee 1966, Nakaya 1954, Nordenskiöld 1893, Schaefer 1949). However, these authors described anywhere from 6 to as many as 80 different types of snow crystals depending on which scheme was examined. To clarify this confusion, international commissions were appointed that have categorized newly precipitated snow crystals into eight basic shapes or subclasses (Colbeck *et al.* 1990, ICSI 1954).

One of the most difficult subclasses to describe accurately are atmospheric snow crystals, which initially form by vapor deposition, but continue to grow by the accretion of minute supercooled cloud droplets. Contact and freez-

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ing of these droplets onto a snow crystal result in a rimed crystal. If the riming process continues until the identity of the original crystal is no longer evident, the resulting crystal is referred to as graupel. The cloud droplets that accumulate on a snow crystal are microscopic, but their accumulation may considerably increase the size and topography of the original crystal. Therefore, the detailed structure of rime and graupel is difficult to observe and photograph with the LM, which has limited resolution and depth of field.

Recently, our laboratory has developed methods that allow us to sample, observe, and photograph snow crystals with a technique known as low-temperature scanning electron microscopy (LTSEM) (Rango *et al.* 1996a,b; 2000; Wergin and Erbe 1990; 1991;1994a,b; Wergin *et al.* 1995; 1996a,b; 1998; 1999; 2002a,b). This technique can be used to magnify snow crystals several thousand times and has a depth of field that exceeds that of the LM by at least 1,000 times (Wergin *et al.* 1998). The current study utilizes LTSEM to describe and characterize rime and graupel.

Material and Methods

Collection Procedure

Data illustrated in this study resulted from five different snow collections during the period of 1995 to 2002 from sites near the following locations: Beltsville, Maryland, Bearden Mountain, West Virginia, Greenwood, Wisconsin, Pinedale, Wyoming, and Fraser, Colorado. The samples that were obtained when the air temperatures ranged from −12° C to 0° C consisted of freshly fallen snowflakes. The collection procedure consisted of placing a thin layer of liquid Tissue-Tek, a commonly used cryoadhesive for biological samples, on a fabricated, flat copper plate measuring 15 × 27mm (Tissue-Tek, Albertville, Minn., USA). The Tissue-Tek and the plate were precooled to ambient outdoor temperatures before use. Next, newly fallen snowflakes were either allowed to settle on the surface of the plate, lightly dislodged and allowed to fall onto its surface, or sampled by gently pressing the plate to the surface of freshly fallen snow. The plate containing the sample was either rapidly plunged into a styrofoam vessel containing liquid nitrogen (LN_2) or placed on a brass block that had been precooled with LN_2 to −196° C. This process, which solidified the Tissue-Tek, resulted in firmly attaching the sample to the plate. Frozen plates containing the samples were inserted diagonally into 20 cm segments of square brass channeling and lowered into a dry shipping dewer that had been previously cooled with LN_2. The dewer containing the samples was conveyed from the collection sites and then either transported by van (from West Virginia) or shipped by air to the laboratory in Beltsville, Maryland. Upon reaching the laboratory, the samples were transferred under LN_2 to an LN_2 storage dewer where they remained before being further prepared for observation with LTSEM.

Preparation for Low-Temperature Scanning Electron Microscopy Examination

To prepare the samples for LTSEM observation, the brass channeling was removed from the storage dewer and placed in a styrofoam box filled with LN_2. A plate was removed from the channeling and placed in a modified Oxford specimen carrier (Oxford Instruments, Enysham, England). The carrier containing the plate was transferred to the slush chamber of an Oxford CT 1500 HF Cryotrans system that had been filled with LN_2. Next, the carrier was attached to the transfer rod of the Oxford cryosystem, moved under vacuum into the prechamber for etching and/or sputtercoating with Pt, and then inserted into a Hitachi S-4100 field-emission SEM that was equipped with a cold stage maintained at −176° ± 20° C (Hitachi High-Technologies Corp., Tokyo, Japan). Accelerating voltages of 500 V to 10 kV were used to observe and record images onto Polaroid Type 55 P/N film (Polaroid, Cambridge, Mass., USA). To obtain stereo pairs, a stage tilt of 6° was introduced between the first and second images.

Conclusion

Low-temperature scanning electron microscopy can be used to illustrate and characterize the frozen cloud droplets, commonly known as rime, which adhere and freeze to snow crystals during formation and descent. This technique shows that rime is found on all types of snow crystals including needles, columns, plates, and dendrites. The droplets vary in size from 10 to 100 µm and frequently accumulate along one side of a single snow crystal, but are found more randomly distributed on crystal aggregations, which are commonly known as snowflakes. Continued accumulation of the frozen cloud droplets leads to the formation of graupel, a particle that frequently measures 1 to 3 mm across and consists of hundreds of frozen cloud droplets that completely engulf the original snow crystal. The frozen cloud droplets are initially encountered as flattened hemispheres on the face of a snow crystal. However, as accumulation continues, they appear more sinuous and elongated, suggesting that aerodynamic forces may influence whether the droplets impact and freeze to the leading face of the snow crystal or are attracted to the trailing face of the crystal as it descends through the atmosphere.