Shape, Composition, and Texture of Cosmic Spherules. M. Doi[1] and T. Nakamoto[2], [1]Tokyo Institute of Technology, [2]Tokyo Institute of Technology (I2-11, Meguro, Tokyo 152-8551, Japan, nakamoto@geo.titech.ac.jp).

Introduction: Cosmic spherules are spherical silicate grains found on Earth. They are collected from polar ice, ocean floor sediments, and stratosphere. They have extraterrestrial origins. When they enter the Earth atmosphere, they are heated by the gas friction and melted. Molten particles become spherical due to the surface tension and re-solidify as they cool to form cosmic spherules. In this study, we focus on cosmic spherules that are once molten completely.

Sizes and compositions of cosmic spherules have been measured [e.g., 1]. Shapes of them (some of them are not perfectly spherical) are also reported [1]. Moreover, some works suggest that the compositions and textures have a relation [e.g., 1]. However, there is no quantitative report on the shape of cosmic spherules. No explanation on the relationship among shape, composition, and texture is present. Those characteristics and relations should be investigated to reveal the nature of cosmic spherules and their formation process. In addition, the formation process of cosmic spherules may have an implication for the formation of chondrules. Therefore, in this study, we attempt to reveal the relationships based on a new measurement of the shape, compositions, and textures, using a theoretical model.

Samples: We use samples collected from Antarctic ice. From ice in the blue ice field at the Cape Tottuki, 903 micrometeorites of sizes in a diameter range from 100 μm to 238 μm were identified based on the surface element abundance obtained by a scanning electron microscope equipped with an energy dispersive X-ray spectrometer. The micrometeorites include fully, partially, and no melted particles. Among them, we only use the fully melted particles, which are cosmic spherules, consisting of stony material in this study. The number of such cosmic spherules is 525.

In addition, we select cosmic spherules that have a smooth surface, because the smooth surface suggests that they are once molten completely. We analyze 50 cosmic spherules with smooth surface. After the measurement of the shape, each sample is polished to have a flat surface and analyzed for major element concentrations by an EPMA. In the analysis, we exclude samples which have cavities or unmelted parts in them. Then, the final number of samples becomes 27.

Measurement of Shape: We approximate the shape of cosmic spherules by three-axial ellipsoids. A three-axial ellipsoid is characterized by three axes: the longest axis is named A, the shorted axis is C, and the rest is B.

The lengths of three axes are measured as follows. First, a sample is placed on a horizontally flat plate and measured two lengths of two axes using a microscope from the top view. Next, by changing the focus of the microscope from the surface of the plate to the top of the sample, the length of the third axis is measured.

Composition and Texture: After the measurement of shape, each sample is potted in epoxy and polished to have a flat section for microprobe analysis. Bulk composition of each cosmic spherule is analyzed by EPMAs at Kyushu University and Tokyo Institute of Technology. Observing the polished section, we can see the texture of each cosmic spherule. Observed textures with compositions are barred olivine, cryptocrystalline, and glass.

Theoretical Model: A motion of dust particles entering the Earth atmosphere from the space is modeled. Our model is similar to that by [2], though the melting temperature of the dust particle in our model is given by the composition of the particle [3]. The compositional change of the dust particle due to the evaporation [4] is also taken into consideration.

The equation of motion takes into account the frictional gas drag and the gas density distribution in the atmosphere. In the energy equation, the heating includes the gas frictional heating and the latent heat, while the cooling includes the radiative cooling, the latent heat, and the thermal collisional cooling with the atmospheric gas. To evaluate the deformation, the ram pressure is also calculated. The degree of deformation is evaluated using the theoretical model by [5].

Results:

Compositions and Textures. Measured compositions and textures are summarized in Figure 1. Red circles and blue squares stand for the barred olivine and crypto crystalline, respectively. Green triangles represent glassy particles. Note that barred olivine and cryptocrystalline particles have lower SiO_2 and olivine-like compositions, while glassy particles have higher SiO_2 content and pyroxene-like compositions. Compositions and textures are tightly correlated as was pointed out by [1].

Plus symbol in Figure 1 corresponds to numerical results obtained by our theoretical model. In the numerical simulations, the initial composition is assumed to be CI. The difference of the numerical results comes from the difference of the entry parameter: the entry velocity and the entry angle to the atmosphere, and the initial size of the particle. Since the Fe is likely to evaporate compared to Si and Mg, as the evaporation proceeds heavily, the composition moves right and down in the diagram. Figure 1 suggests that observed cosmic spherules have not experienced a heavy evaporation. It seems likely that precursors of cosmic spherules with olivine-like compositions are olivine-rich grains, and those with pyroxene-like compositions are pyroxene-rich grains. Initial composition of cosmic spherules seems to determine the final composition and structure.

Shape. The measured shape of cosmic spherules is summarized is Figure 2. Red circles correspond to each sample. Note that C/B = B/A = 1 means a perfect sphere. A red colored region represents an expected area by our theoretical model. We can see that most of samples have shapes consistent with our model (within an error). However, some samples have smaller deformation than the theoretical model. This suggests that those samples re-solidified under the ram pressure that is lower than our model estimates. This may happen if the grain does not re-solidify even under the melting temperature and experiences the super cooling, because the grain falling in the atmosphere is decelerated so the grain temperature, the velocity, and the ram pressure decrease as the grain falls. We have also realized that less deformed spherical cosmic spherules have glassy textures and pyroxene rich compositions. This seems consistent with our theory: the ram pressure drives the deformation.

Summary: We have measured the size, shape, compositions, and textures of cosmic spherules. Also, we have developed a theoretical model simulating the temperature, evaporation, compositional change, size change, and deformation. Comparing measurements and theoretical results, we have found that (1) cosmic spherules do not experience heavy evaporation, so the initial compositions are mostly preserved, (2) olivine-rich particles form crystalline cosmic spherule, while pyroxene-rich particles form glassy cosmic spherules, (3) shape of cosmic spherules are determined by the ram pressure at the moment of the solidification, and (4) pyroxene-rich particles are likely to experience the super-cooling and lower ram pressures, so they have low deformation.

References:

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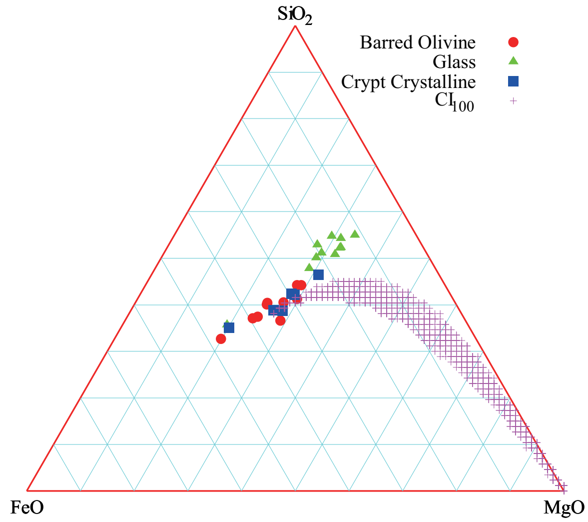

Figure 1: Compositions and textures of cosmic spherules. Red circles, blue squares, and green triangles show measured results. Plus symbols represent theoretical results with initial composition of CI.

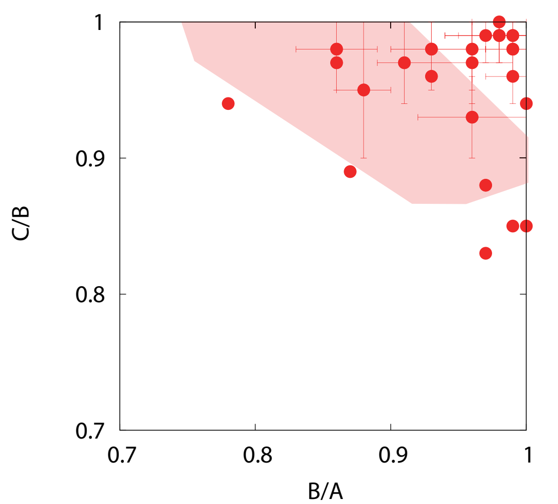

Figure 2: Degree of deformation of cosmic spherules: measured (circles) and theoretically expected (colored region).