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Three-dimensional shapes of cosmic spherules: Deformation of dust particles molten in the earth atmosphere

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Cosmic spherules are extraterrestrial-origin round-shaped dust particles collected from the stratosphere, polar ice, and ocean floor sediments. When extraterrestrial dust particles enter the Earth atmosphere, they are heated by the gas friction and melted. Because of the surface tension, the molten particles become spherical and form cosmic spherules when they solidify. They are thought to originate from asteroids or comets and caught by the Earth.
Tsuchiyama et al. (2003) have examined 3-D structures of cosmic spherules and found that there are both prolate (Rugby-ball like) and oblate (pancake-like) shapes. Also we have examined 3-D shapes of cosmic spherules and found that they have deformed with a large variety. The ram pressure, the surface tension and the centrifugal force acting on the particles deform the shape when they are molten. Thus, it seems natural to consider that the variation of the observed cosmic spherule shapes may originate from the shape of dust particles when they solidified. Especially, the differences of the liquidus temperature among cosmic spherules may generate the variety of deformations.
In this study, we measure the 3-D shapes of more cosmic spherules to extend the number of samples and analyze their major element concentrations to estimate the liquidus temperature. Then we evaluate the ram pressure and the centrifugal force when the dust particles solidify by solving the equation of motion and the energy equation of the dust particles entering the Earth atmosphere. We examine the cases with a wide variety of entry parameters: the initial radius (from 0.1 mm to 2 mm), the entry velocity (from 11.2 km/s to 20 km/s), and the entry angle (from 0 to 90 degrees, the angle 0 corresponds to the entry from the zenith direction). And we calculate the magnitude of deformation of the dust particles by using analytic solutions for the shape of the molten particles. Finally, we compare the results of calculations with observations.
When a molten dust particle does not rotate, it forms oblate shape due to the ram pressure from one direction (Sekiya et al. 2003). On the contrary, when a molten dust particle rotates fast, it forms prolate shape (Miura et al. 2008). In this study, we define the magnitude of the deformation of the molten particle as X = {(1-B/A)^2 + (1-C/B)^2}^1/2, where A, B, and C are axial radii approximated as three-axial ellipsoid (A ? B ? C). To calculate X, we use the analytic solutions both for the fast rotating molten particles and for the no rotating molten particles.
We measure three axial radii (A, B, and C) of once molten stony cosmic spherules, which are collected from Antarctica, in a radius range between 0.04 mm and 0.12 mm. After the shape parameter measurement, each spherule was polished to have a flat surface and analyzed for major element concentrations using an electron microprobe analyzer. Then, we calculate the liquidus temperature using the model by Hewins et al. 1993.
We can see a good correlation between the X and the liquidus temperatures among samples, i.e., natural cosmic spherules have large deformed with higher liquidus temperature. Our numerical results show the consistency with measurement results. In our model, the magnitude of the deformation of the oblate spherules is larger than that of prolate spherules, because the ram pressure acted on rotating particle is averaged with respect to azimuth angle and is one-fourth times lower than that of particle from one direction. The measurement results are consistent with

our model, i.e., the magnitude of deformation of oblate spherules is larger than that of prolate spherules. So, it seems that their shapes depend on whether or not the particle is rotating while it is melting. Also, the magnitude of the deformation of some samples is less than that of numerical results. One of the possibilities is that they are re-solidified below the liquidus temperature, i.e., they have experienced supercooled state.

Keywords: Cosmic spherule, deformation, gas frictional heating