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Three-dimensional size distributions of voids and metal/sulfide grains in chondrules and their origin

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Chondrules are one of the major constituents of primitive meteorites. They have been extensively examined to understand their formation process and discuss the evolution of the primordial solar nebula. Their 3-D structures have been examined by X-ray CT using synchrotron radiation at SPring-8 (SP-microCT) [1]. It was proposed from their external shapes and internal distribution of voids and metal/sulfide grains that chondrules were rotating at high speed of about a few hundreds rps during their formation [2].

In the present study, size distributions of voids and metal/sulfide grains in the chondrules imaged by [2] were examined and formation processes of the voids and the metal/sulfide grains were discussed. We examined 22 chondrules, which were removed from the Allende meteorite (CV3). Voids and metal/sulfide grains were recognized by thresholding CT values, which correspond to linear attenuation coefficients of materials in CT images. Particles having larger than 10 voxels (the voxel size is 5.83 um3) were regarded as voids or metal/sulfide grains by taking image noises into consideration. Most of the chondrules have more or less voids (0-2.8 vol.%) and metal/sulfide grains (0-6.8 vol.%). We selected chondrules having more than 100 particles (8 and 11 chondrules for voids and metal/sulfide grains, respectively). Equivalent diameters of their particles with respect to the volumes, L, were calculated and their number density distributions, n(L), were obtained three-dimensionally. Void sizes have exponential distributions, where log(n) is proportional to n, except for a few large voids. On the other hand, metal/sulfide grain sizes seem to have power distributions, where log(n) is proportional to log(L) (the power is about 1.5-3).

If a chondrule melt was rotating, voids and metal/sulfide grains should be moved inward to and outward from the rotation axis, respectively, by centrifugal force. The time scale for the movement by centrifugal force is sufficiently shorter than the time scale for cooling of chondrules. If voids and metal/sulfide grains were present at the time of chondrule melt formation, voids and metal/sulfide grains should be reached to the rotation axis and the surface, respectively, in a barred olivine (BO) chondrule, which once experienced perfect melting. In fact, metal/sulfide grains were present only at the surfaces of three BO chondrules. These metal/sulfide grains were precursors and incorporated into the chondrules. Their power size distributions can be explained by destruction of metal/sulfides before chondrule formation. On the other hand, voids are not perfectly on the rotation axis although they are concentrated near the rotation axis. This shows that voids, such as by incorporation of openings in a dust ball precursor, were absent at the time of melting but voids were formed after BO crystallization. Actually, bubbling occurred by supersaturation of volatile component in a melt due to olivine crystallization, the bubbles were trapped on the platy olivine crystals and they were not accumulated along the surface perfectly. The exponential size distributions of the voids are consistent with the distributions formed by nucleation and growth of particles. In fact, crystal and bubble sizes in igneous rocks usually have exponential distributions [3]. However, exponential distributions by nucleation and growth in closed systems are not self-evident although the CSD theory [4] for open system crystallization gives exponential distributions. We do not know the actual reason for exponential distributions even in closed systems. Volatile components for the bubbling might be moderately volatile elements, such as alkalis and sulfur although we cannot exclude the possibility of water.

[1] Uesugi et al. (1999) Proc. SPIE, 3772, 214. [2] Tsuchiyama et al. (2002) Abstract in JMEPS; Tsuchiyama et al. (2003) LPSC, XXXIV,1271. [3] Morishita (1992) Kazan, 6, 285-293. [4] Marsh (1988) CMP, 99, 277-291.