Vesicles in chondrules: reproduction experiments, simulation and comparison with natural chondrules

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Three-dimensional structures of chondrules by X-ray CT [1] shows that small amounts of vesicles (below 3 vol.%) are commonly present in chondrules. Thus, vesicles are one of the important constituents in chondrules as well as silicates, metals and sulfides. In order to elucidate vesicle formation in chondrules, the authors have made their reproduction experiments [2]. In the experiments, aggregates of minerals grains (below 50 microns) were heated at one atmosphere by assuming chondrule formation from dust balls. Vesicles in the run products were analyzed as a function of temperature and time using X-ray CT (effective spatial resolution is about 10 microns), and their sections were observed under an SEM. With increasing the degree of partial melting, porosity decreases, connectivity of vesicles [3] increases, and the number density of vesicles decreases. These results can be explained by aggregation of vesicles and escape of some vesicles outward from the melt surface. The size distribution of vesicles changes from an exponential distribution to a power distribution via intermediate distributions with increasing the degree of partial melting.

As we do not understand details of time development of the vesicle textures at constant temperatures, computer simulations were made two-dimensionally, where the initial vesicle size immediately after melting is assumed to obey an exponential distribution. In the simulation, vesicles with such size distribution were distributed randomly in a space first, move randomly to aggregate into larger particles or escape from the melt surface. The relation between the size distribution change and the size dependence of the moving velocity were examined. The size distribution changes to a power distribution only when larger vesicles move faster than smaller ones. The porosity and the connectivity also changed similarly in the experiments. The results show that the size distribution change can be attributed to time development of the vesicle textures during melting. In the experiments, remnant crystals against melting (about 30-50 microns) are present. The motion of smaller vesicles than the crystals should be interrupted by the crystals, while that of larger vesicles not because the larger vesicles can move in a fluid of melt and crystal mixture. This is consistent with the simulation results.

Image analysis of the tree-dimensional structure of chondrules from the Allende meteorite [1] shows the chondrules have exponential or power distribution of the vesicle size. Chondrules with the exponential distributions have lower connectivities and higher number densities of vesicles than those with the power distributions. This is consistent with the experimental results. The present results suggest that the difference of the vesicle size distribution corresponds to the different states of the vesicle texture development. On the other hand, the experiments cannot reproduce the low porosities of chondrules. If vesicles in chondrules were formed by closure of vacancies in dust balls during melting, such vesicles shrink by the surface tension of the melt. The degree of shrinking is almost negligible at one atmosphere, while it is large at low pressures, where chondrules were formed (e.g., 0.0001 atm). The low porosities of chondrules can be explained by this shrinking at low pressures. Although details should be discussed by melting experiments at low pressures, the present study shows that vesicles in chondrules are consistent with chondrule formation by heating of dust balls.

[1] Tsuchiyama et al. (2003) LPSC, XXXIV, 1271. [2] Nakajima et al. (2005) Abstracts 2005 JEPS Joint Meeting, Annual meeting of Planetary Society of Japan. [3] Ikeda et al. (2000) Mineral. Magazine, 64(5), 945-956.