COMPOUND CHONDRULE FORMATION VIA HIGH-SPEED COLLISION OF SUPERCOOLED DROPLETS IN OPTICALLY THIN SHOCK WAVES.

S. Arakawa[1] and T. Nakamoto[1], [1]Department of Earth and Planetary Sciences, Tokyo Institute of Technology, 2-12-1 Ookayama, Meguro, Tokyo 152-8551, Japan. Email: arakawa.s.ac@m.titech.ac.jp.

Introduction: Chondrules are millimeter-sized spherules contained within chondrites as a major component and some chondrules, referred to as compound chondrules, are composed of two or more chondrules stick together. Although the formation mechanism of compound chondrule is still under debate, most of the previous studies interpreted the presence of compound chondrules as the result of collisions [e.g., 1−4]. The ubiquitous existence of cratered chondrules also suggests that some of the chondrules have experienced collisions before the accretion onto parent bodies [1]. Wasson et al. [5] classified each constituent chondrules as primary or secondary. Primary chondrules keep their spherical shape while secondary chondrules are deformed. Compound chondrules with blurred boundaries are rare within ordinary chondrites [5], indicating that compound chondrules are formed by collisions between crystallized and non-crystallized precursors [3].

The textures of compound chondrules have noteworthy features. Wasson et al. [5] reported that ~ 80% of primaries and ~ 90% of secondaries are nonporphyritic chondrules while only 15% of all chondrules in ordinary chondrites are nonporphyritic [1]. Therefore, compound chondrules are selectively formed from the precursors of nonporphyritic chondrules. Crystallization experiments [6] revealed that completely molten precursors turn into supercooled droplets as they are cooled below their liquidus temperature, and they crystallize immediately once these supercooled droplets collide with other particles [7]. Then we can imagine that compound chondrules are formed when crystallized chondrules and supercooled precursors collide and stick together [3].

Numerous ideas are proposed as chondrule formation mechanisms, including shock-wave heating [e.g., 8], planetesimal collisions [e.g., 9], and radiative heating by lightning [e.g., 10], and shock-wave heating within the solar nebula is one of the leading candidates. In this study, we examine the possibility of compound chondrule formation via collisions of supercooled precursors in shock waves.

Results and discussion: We calculated the velocity and the temperature of chondrules in one-dimensional normal shocks. For the case of optically thick shock waves, chondrules are thermally coupled with gas in post-shock regions [11], and collisions of chondrules would occur when the temperature is above their liquidus temperature. In this case, molten chondrules cannot avoid collisional destruction [12] and compound chondrules might not be formed.

In contrast, chondrule precursors can maintain their supercooling until the fine dust grains condense and accrete onto supercooled droplets in optically thin shock waves. Using a viscosity-temperature relation of chondrule melts [13], the critical velocity for collisional sticking would be higher than 1 km s^{-1} when the temperature of supercooled droplets is lower than ~ 1400 K. Therefore, compound chondrules can be formed in post-shock regions of optically thin shock waves.

Bow shocks caused by 100−1000 km-sized planetary bodies with eccentric orbits [e.g., 14] may be potent candidates for the sources of optically thin shock waves because the optical depth of the chondrule-forming region is lower than or on the order of unity when the dust-to-gas mass ratio is the solar metallicity [15]. The collision frequency between crystallized chondrules and supercooled precursors is also consistent with the fraction of compound chondrules in nonporphyritic chondrules [15].

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