Possibility of chondrule formation by nebular shock waves: Distribution of iron inclusions in chondrules melted by a shock wave

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The nebular shock wave heating model is thought as one of the most probable model of the chondrule formation. The advantage of the model is that the thermal history of a chondrule obtained from numerical calculations of the nebular shock wave heating model agree well with results of chondrule texture reproduction experiment.

We examined the validity of the nebular shock wave model from a viewpoint of iron inclusions of chondrules. Recently, Uesugi et al. (2003) have shown that strong apparent gravitational force (around 20 G, G is gravitational acceleration on the earth' s surface) acts on the melted chondrule due to the drag deceleration by the shocked nebular gas. And also, a high speed internal flow (around 5 cm/s) is driven by tangential component of momentum flux of the shocked nebular gas flow after total melting of the chondrule. Based on these results, we calculated the trajectories of molten iron inclusions in a melted chondrule. The results show that molten iron inclusions with radii larger than 0.2 times that of chondrule are quickly (around 0.1 s) reach the surface of the chondrule from inside due to the centrifugal force of the rotational flow. Previous studies of nebular shock wave heating model have shown that the duration of melting for nebular shock heating to be around seconds to minutes. Thus, the time scale is one or more orders shorter than the duration of chondrule melting, and all such iron inclusions must be on the surface of the chondrule in absence the effective processes of returning back the iron inclusions from surface to inside of the chondrule. However, any processes would not be able to make it possible returning back iron inclusions from surface to inside of the chondrule, because the surface energy of melted chondrule and iron inclusion holds the iron inclusions on the surface of the chondrule so strongly.

We also observed iron inclusions in chondrules. From thin section observation, iron inclusions being inside of chondrules and would have radii larger than 0.2 times those of the chondrules were observed. We also observed iron inclusions using X-ray CT system, and found that iron inclusions are actually inside of the chondrule and have radius ratio larger than the critical value. From these results, the chondrule formation by nebular shock waves are considered to be unlikely.