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An experimental study on the formation of the type I chondrules

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Introduction: Chondrules have been reproduced at 1 bar under the IW-0.5 oxygen pressure, where FeO-rich, type II chondrules are produced. Although type I chondrules have been experimentally examined by Cohen and Hewins (2004), the charge was quenched and dissimilar to natural chondrules. In the present study, chondrules were reproduced under the condition of the IW-3 to -5 with the various cooling rates mainly of 100 oC/h, where FeO-poor, type I chondrules are produced.

Experiments: Three kinds of sintered pellets of homogenized powders with chondritic compositions were prepared as starting materials of the present experiments; (1) Allende CV3.2, (2) NWA 1465 (a carbonaceous chondrite), and (3) powder mixtures including iron, olivine, enstatite, anorthite, and diopside. The peak temperatures of the runs 1200-1550 oC and the cooling rates 80-10000 oC/h. Two cases were considered in the use of silica powder as Si-rich gas source and in the absent of the silica powder. The furnace was low pressure type controlling below the atmospheric pressure under the reduced condition, whose pressure was controlled to be mainly 100 Pa. The capsule made of alumina has an orifice (1 mm) on the top and the charge is held using the Mo-wire of 0.2 mm in diameter in the capsule. Silica was put on the bottom of the capsule for its use The vapor pressure from the charge and silica in the capsule is about 1 Pa at ˜1450 oC of the peak temperature. When the furnace total pressure is controlled to be 100 Pa using the hydrogen gas, the hydrogen gas enters into the capsule balancing the outside of the capsule. The oxygen pressure is IW-3 in the case of the existence of silica powder, and IW-4 in the absence of the silica powder at 1450 oC. The starting materials (1) and (2) correspond to the metallic iron poor starting materials and the runs of 53 times were carried out (23 times with Si-rich gas and 30 times without Si-rich gas). The starting material (3) corresponds to the metallic iron rich starting materials and the runs of 21 times were carried out (11 times with Si-rich gas and 10 times without Si-rich gas). The polished sections were made from the run produces, and observed and analyzed using an electron probe micro analyzer (EPMA, JXA-8200).

Results and discussion: Poikilitically enclosed rounded forsteritic olivines in porphyritic enstatites formed from metallic iron poor starting materials at the peak temperature of 1450 oC and the cooling rate of 100 oC/h, which is similar to type I chondrules. The rounded olivines are relict phase, dusty olivines and forsterites, common in chondrules. The texture of the runs with Si-rich gas source is similar to the type I chondrules. Although kamacite droplets enclosed in olivines and pyroxenes are usually abundant in type I chondrules, they are not common in the run products. The iron content of the run products decreased. Since the volume of the absorption of iron into the Mo wire is much less than the volume of compositional change, the significant of the iron oxide component directly evaporated but not the reduction into metallic iron.

Metallic iron melt tends to aggregate into a clump at the peak temperature more than 1500 oC from metallic iron rich starting materials. The metallic iron was dispersed in the charge due to the low melting degree at the peak temperature less than 1500 oC, but the iron was deficient on the charge surface, suggesting the evaporation of iron. The textures are not similar to chondrules.

Considering the present experimental results, we may prefer the metal-deficient precursors for the type I chondrules rather than metal-bearing precursors. However, the origin of kamacite droplets enclosed in Mg-rich olivine and pyroxenes in type I chondrules is still unclear. They may be originated from the injection during the chodnrule melting or the iron vapor was saturated during the chondrule melting.

Reference: Cohen B. A. and Hewins R. H. 2004. GCA, 68, 1677-1689.

Keywords: chondrule, type I, chondrule formation, reproduction, experimental study