

CRYSTALLIZATION OF TYPE B CAI MELT IN LOW-PRESSURE HYDROGEN GAS AND IMPLICATIONS FOR FORMATION CONDITIONS OF IGNEOUS CAIs.

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Introduction: CAIs are the oldest objects formed in the early Solar System. Chemical and petrological characteristics observed in some CAIs show that they formed through high-temperature processes such as melting and evaporation, followed by crystallization. Many laboratory and theoretical studies have discussed evaporation and crystallization of CAI melts (e.g., [1-4]), but crystallization of CAIs in the presence of nebula-like low pressure hydrogen gas, where evaporation and crystallization take place simultaneously, has not yet been fully understood. In this study, crystallization experiments of type B CAI-composition melts at low hydrogen pressures were conducted to investigate the effect of evaporation during crystallization of type B CAIs and to constrain the formation conditions of type B CAIs.

Experiments: The starting material was prepared by mixing SiO₂, TiO₂, Al₂O₃, MgO, and CaCO₃ powders to make a composition named CAI_χ. This is a composition on the condensation trajectory of [4] and a possible precursor for type B1 CAIs. Premelted glassy spherical samples on Ir wire loop (2.5 mm in diameter) were used as starting materials. The experiments were conducted at Hokkaido University using a vacuum furnace equipped with a hydrogen gas flow system. Cooling experiments were conducted from 1420°C to 1120–1277°C at controlled cooling rates of 5–50°C/hr and under 3 different pressures (P_{H_2} =10, 1, 0.1 Pa) to examine the pressure dependence of compositional and textural change. All the samples were quenched after each run. Run products were weighed and mounted into epoxy resin and then polished to expose the cross section of the samples. Textural observation and quantitative analysis were conducted by FE-SEM (JEOL JSM-7000F) with EDS at Hokkaido University.

Results and discussions: All the run products showed the compositional change due to evaporation of mainly MgO and SiO₂ components, and their measured bulk compositions were within the compositional field of type B CAIs. Weight losses of the samples indicated that the degree of evaporation increases at a higher P_{H_2} or with a slower cooling rate. However, the evaporative loss at higher P_{H_2} is less than expected from the lower P_{H_2} experiment considering that the evaporation rate is proportional to the square root of P_{H_2} [5]. In the samples evaporated at P_{H_2} = 10 Pa, their outer regions are relatively enriched in melilite, as observed in natural type B1 CAIs, compared to the samples heated at P_{H_2} of 1 and 0.1 Pa. The compositional zoning of the melilite near the sample rim (melt droplet surface) shows that it becomes Mg-rich toward the inside, suggesting that these melilites crystallized inward from the melt droplet surface. This could be attributed to the difference in P_{H_2} dependence of evaporation rate and elemental diffusion rate in the melt; evaporation is enhanced by hydrogen, while diffusion is not. At higher P_{H_2} (i.e., 10 Pa), evaporation could occur faster than diffusive homogenization of the melt, resulting in effective crystallization of melilite near the melt droplet surface enriched in Ca and Al. The crystallization of melilite at the droplet surface prevents further evaporation of the melt, which explains the lower degree of evaporation at 10 Pa than expected. The present experiments suggest that type B1 CAIs with melilite rim formed at P_{H_2} of ~10 Pa or higher, while type B2 CAIs without melilite mantle formed at <10 Pa, which is consistent with the prediction by [3]. The fluctuation of disk gas pressure may have been responsible for the formation of type B1 and B2 CAIs.

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