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原始太陽系星雲の高温過程で形成された棒状カンラン石コンドリュールの再現実験

Reproduction experiments of barred olivine chondrules formed at high-temperature process in the solar nebula

森田朋代 [1]，中村智樹 [1]，小山千尋 [2]，三浦均 [3]，木村勇気 [4]，渡邉華奈 [1]，土山明 [5]
Tomoyo MORITA[1], Tomoki NAKAMURA[1], Chihiro KOYAMA[2], Hitoshi MIURA[3], Yuki KIMURA[4], Kana WATANABE[1], and Akira TSUCHIYAMA[5]
[1] 東北大学，Tohoku Univ.,
[2] 宇宙航空研究開発機構，JAXA,
[3] 名古屋市立大学，Nagoya City Univ.,
[4] 北海道大学，Hokkaido Univ.,
[5] 立命館大学，Ritsumeikan Univ,

1. Introduction

Chondrules are sub-millimeter-sized spherical objects abundantly found in primitive meteorites[1)]. They are thought to have formed from completely or partially molten silicate melts that experienced transient heating (up to ~2000 K), followed by rapid cooling[2)]. Their characteristic textures record the thermal history of energetic processes that occurred in the early solar system. However, the precise formation process and heating mechanism of chondrules remains an open question.

In this study, we focus on a specific type of chondrules called barred olivine (BO) chondrules. BO chondrules were formed from completely molten droplets and thus are ideal objects for reflecting the high-temperature process involved in chondrule formation[3)]. Moreover, their melting and crystallization process are relatively simple and uniquely determined. Therefore, our aim is to constrain their formation process by experimental reproduction of the texture of BO chondrules. Our research group plans to carry out BO chondrule reproduction experiments using the Electrostatic Levitation Furnace (ELF) aboard the International Space Station (ISS). Prior to these space-based experiments, we conducted ground-based experiments using a gas-jet levitation system to determine the appropriate temperature conditions for the ISS experiments.

2. Gas-jet levitation system on the ground-based experiment

We used a gas-jet levitation system at the Japan Aerospace Exploration Agency (JAXA). In this method, a sample was floated by blowing gas and heated by CO_2 laser. The starting materials were prepared as a mixture of reagent-grade oxide (1.74 wt.% Na2O, 34.73 wt.% MgO, 8.60 wt.% Al2O3, 42.78 wt.% SiO2, 4.73 wt.% CaO, 6.72 wt.% FeO, and 0.70 wt.% NiO) based on the natural BO composition [4-6)]. Experiments were conducted in an Ar gas atmosphere at 1-2 atm to prevent oxidation of starting materials. The temperature was measured by a thermal infrared thermometer, and the crystallization behavior was observed by a CCD camera and a high-speed camera. After reproduction experiments, the samples were embedded in epoxy, polished, and analyzed by a field emission electron microscope at Tohoku University.

The experimental procedure was as follows: First, the starting materials were levitated and heated above the liquidus temperature (1603 ± 10 °C) to melt completely. Then the molten droplets were cooled to a supercooled state (1300, 1200, 1100, 1000, and 900 °C) at a 1-10 °C/s cooling rate and shacked by changing gas flow in order to trigger crystallization. After the crystallization was completed, the sample was quenched or held temperature of crystallization for 1-60 min in the experiments at 1300 °C.

3. Results and discussion

We reproduced a variety of olivine bar textures observed in natural BO chondrules and found the textural variation depends on the crystallization temperature: (1) radiating barred crystals formed at 1300 °C, (2) parallel barred crystals at 1100–1200 °C, and (3) small dendritic crystals at temperatures below 1000 °C. All experimental products did not form rim crystals that are usually observed in natural BO chondrules (Fig. 1). However, the rim crystals covering almost the entire surface were developed in the sample that was continuously heated at 1300 °C after crystallization. The thickness of the olivine rim crystals increased with the square root of the retention time $t^{1/2}$, suggesting that the rim texture of BO chondrules reflects the temperature conditions of the post-crystallization annealing process.

4. Future ISS experiments

In this study, we successfully reproduced the BO texture, but some limitations remain. In the ground-based experiments, the samples were rotated to counteract gravity in order to keep the droplet levitated, and convection within the melt was dominant. These effects may cause variations in the temperature distribution and the rate of mass transport within the melt, making it difficult to estimate their influence on crystal growth. Therefore, we plan to conduct reproduction experiments of BO chondrules under microgravity conditions in the ISS with the same temperature profiles we applied for the experiments under gravity, enabling a direct comparison of texture development in the presence and absence of gravity.

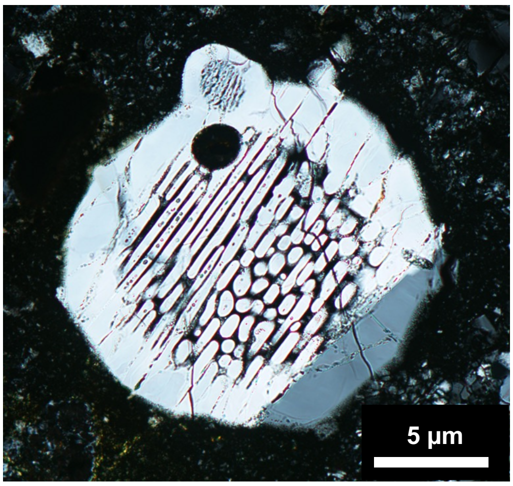

Figure 1. Barred olivine chondrule under polarizes light microscope.

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