NONEQUILIBRIUM SPHERULITIC MAGNETITE IN THE RYUGU SAMPLES

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Introduction: Samples returned from the carbonaceous asteroid 162173 Ryugu by the JAXA Hayabusa2 mission allow us to investigate primitive materials of our Solar System and their evolution [1-2]. Recent studies have shown that the Ryugu samples are composed of minerals similar to those of CI (Ivuna-like) carbonaceous chondrites indicating that the parent planetesimal from which Ryugu was derived experienced severe aqueous alteration [e.g., 1-2]. Our previous study described that magnetite in the Ryugu samples from chamber A occurs as framboids, plaquettes, spherulitic, and irregularly shaped grains [3-5]. They are products of alteration, and their formation is controlled by variation in the diffusion and growth rates during aqueous alteration on the parent body [4]. In this new study, we focus on spherulitic magnetite grains in the Ryugu from chamber C to understand the evolution of the aqueous alteration processes on the carbonaceous (C-type) asteroids [4].

Samples and Methods: Multiple spherulitic magnetite grains were identified embedded in the fine-grained materials returned by the Hayabusa2 spacecraft collected during both touchdowns (chambers A and C). Figure 1 shows the spherulitic magnetite (~13 µm in diameter) analyzed in this study and collected during the second landing operation (chamber C, C0105-039024). The grain is associated with fine-grained phyllosilicates, euhedral sulfides, and framboidal magnetites Fig. 1). We prepared one FIB section for electron microscopy studies using the Helios 660 dual-beam focused ion beam SEM (FIB-SEM) instrument at the University of Hawai'i at Mānoa and examined the section by transmission electron microscopy (TEM) using the JEOL NEOARM 200CF at the University of New Mexico.

Results: The spherulitic magnetite has an internal texture composed of individual radiating fibers varying in length from 5 µm to 8 µm. The fibers radiate from a spherical pore (Fig. 1c, ~130 nm in diameter) located off-center. The widths of the fibers vary in size from 70 nm to 140 nm. The spherulitic magnetites are characterized by high porosity, with randomly distributed pores ranging from a few nanometers up to 2.2 µm in size; however, the magnetites with other morphologies (e.g., framboidal magnetite) are free of pores. Most pores are euhedral to subhedral in shape, located inside the fibers or at their boundaries. Additionally, we identified an amorphous rim (80- 350 nm in thickness) composed of 5 wt % Si, 4 wt% S, 2 wt% P, and 13 wt% C around the magnetite grain.

Discussion: Spherulitic textures are common in terrestrial and extraterrestrial samples [6]. They were previously described in CI chondrites and the Ryugu samples collected during the first landing operation (chamber A) [4, 6]. This particular texture suggests that spherulitic formation requires crystallization from an amorphous material under conditions that maintain a subtle balance between the diffusion rate and the growth rate of the crystal itself [6]. An aqueous gel containing a colloidal Fe hydroxide probably supplied the requisite amorphous medium for spherulitic growth. Our study suggests that the aqueous fluid from which these spherulitic magnetites crystalized probably contained in addition to Fe hydroxide, also Si, S, P, and C, as indicated by the chemical composition and the texture of the amorphous rim identified around the spherulitic magnetite. The presence of pores and radiating fibers in the internal texture are characteristic of rapid growth processes under nonequilibrium conditions [6]. Their formation could have been triggered by energetic impacts during post-accretional impact events, as indicated recently for the formation of framboidal magnetite in Tagish Lake [7].

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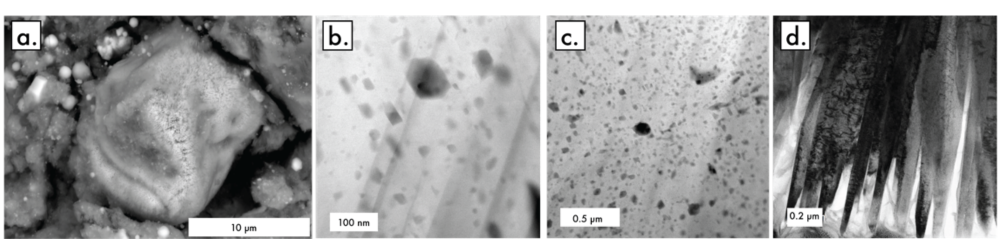

Figure 1. Backscattered electron (a), dark-field STEM (HAADF, b-c), and bright-field TEM images of the spherulitic magnetite analyzed in this study. The TEM data show the texture of the radiating fibers and the random distribution of euhedral to subhedral pores.