C型小惑星リュウグウ試料に含まれる無水鉱物の宇宙風化組織

Space weathering features of anhydrous minerals in fine grains from the C-type asteroid Ryugu.

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Introduction: Materials exposed to the space environment are expected to show optically and chemically modified properties. This process is called as space weathering and is caused mainly by micrometeoroid bombardments and solar wind implantation [1]. Thus far, the space weathering of carbonaceous asteroids has not been well understood. Regolith samples were successfully recovered from C-type asteroid Ryugu by the Hayabusa mission [2]. Ryugu samples will provide insights into the ongoing space weathering of Ryugu [3]. In this study, we investigated the space weathering of anhydrous minerals including iron sulfides, magnetite, and carbonates, which are major reservoirs of volatiles including carbon, oxygen, and sulfur in Ryugu materials. We performed scanning electron microscopy (SEM) and transmission/scanning transmission electron microscopy (TEM/STEM) analysis for Ryugu samples

Results: The space-exposed surfaces of Ryugu grains were identified by the appearance of impact craters, melted attachments on the grain surfaces. We found modified pyrrhotite and pentlandite having shallow depressions or porous textures. Iron metals are developed on the iron sulfide surfaces, and some are in the form of curved whiskers. The iron whiskers include small amounts of nickel. TEM analysis shows that the iron metals are body-centered-cubic (bcc) iron. The modified surface of magnetite exhibits a porous texture. TEM observation shows that bcc metallic iron particles cover the magnetite surface. This metal-rich rim extends to approximately 60 nm from the surface. Beneath the metal-rich layer, crystallographic misorientations extend to a depth of 120 nm. The modified surface of breunnerite grain is covered by ferropericlase [(Mg,Fe)O] -rich rim. Crystallographic misorientations appear in the substrate breunnerite within 130 nm below the surface. Dolomite has a vesicular rim with crystallographic misorientations. Carbon and oxygen are depleted at the surface of these carbonates.
Discussion: Metallic iron whiskers on iron sulfides have been found as space weathering products in regolith particles from the S-type asteroid Itokawa [4] and lunar soils [5]. The metallic iron might have formed through selective sulfur loss that leads to the accumulation of excess iron atoms and the growth of iron metals. These alterations are likely caused by solar wind implantation and micrometeoroid bombardments [4]. The lattice misorientations and vesicles identified in the modified magnetite and carbonates likely correspond to typical damage structures in crystals irradiated by solar wind [6]. The iron metals on magnetite may have been formed via the selective escape of oxygen by ion sputtering and by the thermal effects of micro-impacts. In addition, the solar wind sputtering and micrometeorite bombardments may have caused the selective escape of carbon and oxygen at the carbonate surfaces,

resulting in the formation of the periclase-rich rim on breunnerite. Considering our results and space-weathered phyllosilicate that exhibits dehydration and iron reduction [3], the loss of volatiles and the resultant reduction of iron may represent the major modification of space weathering ongoing on the surface of Ryugu. We suggest that these modifications are distinct indicators of the progress of space weathering on volatile-rich airless bodies.

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