Space weathering of iron sulfides on airless bodies

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Introduction: Solar wind implantation, micrometeorite impacts, and solar radiation cause the alteration of the optical, physical, and chemical properties of surface materials on airless bodies. Space weathering refers to these alteration processes, which affect rocks and soils on airless surfaces over time [1]. Microstructures indicative of space weathering are important in understanding geological processes occurring in the dynamically evolving regolith, such as regolith motion, volatile distribution, and replenishment of soils [2]. Space weathering features also shed light on the evolution of solids in interstellar environments and at the surface of the proto planetary disk, where free-floating particles could be bombarded by energetic ions. Extensive studies of lunar soils and particles from S-type asteroid Itokawa have revealed microproducts caused by space weathering, such as vapor depositions, partly/completely amorphized rims, and nanophase iron/iron compounds [e.g., 3, 4]. Our knowledge of space weathering has progressed based on analyses of the major constituents of rock forming minerals such as silicates and oxides, whereas the behavior of other minerals in space-exposed environments remains poorly investigated. Iron sulfides represent solid reservoirs of sulfur, which is a major, moderately volatile element in early solar system materials. The space weathering features of iron sulfides will provide clues to understanding the evolution of sulfur compounds and the distribution of sulfur on airless bodies. Here, the author reports recent studies on space weathering of iron sulfides in lunar soils and Itokawa particles using electron microscopy techniques [5, 6].

Methods: Itokawa particles and lunar mare soils from Apollo 11 and 17 landing sites were used in the studies. The sizes of the samples are smaller than 200 µm. Itokawa particles have mineral components corresponding to those of LL chondrites, and contain 2 vol% of iron sulfides [7]. Lunar mare basalts include < 1 wt% of iron sulfides, with the sulfur content being higher in mare basalts than in highland rocks [8]. Surface structures of iron sulfides were observed using scanning electron microscopy (SEM). Then, electron-transparent sections were prepared using focused ion beam (FIB) systems from regions of interest on the samples. The sections were analyzed using transmission electron microscopy (TEM).

Results: SEM observations revealed that altered surfaces of iron sulfides have vesicular textures and elongated iron metals (whiskers) on their surfaces (Fig. 1). These microstructures were identified in Itokawa particles and lunar soils and are similar to each other. TEM analysis showed that the upper zone of iron sulfides from the surface to a depth of up to 80–100 nm is distinct from the non-altered area; this zone is defined as the space-weathered rim. The space-weathered rim is characterized by crystallographic misorientations and the disappearance of superstructure reflections of troilite in electron diffraction patterns. The rim contains opened vesicles that are aligned along the c-plane of the sulfides, as well as numerous tiny vesicles. The Fe/S ratio on the surface of the rim is higher than in non-altered regions, indicating selective sulfur loss from the surface. Iron whiskers protrude from the space-weathered rim and consist of polycrystalline metallic iron. The sulfide rims and the iron whiskers are both coated with vapor-deposited materials.

Discussions: The crystallographic modifications of the sulfides are probably produced by solar wind irradiation. The loss of sulfur atoms may be caused by combined processes including selective sputtering of sulfur atoms during solar wind implantation, chemical reaction with solar wind hydrogen, and thermal effects produced by micrometeorite bombardments. The whiskers may have been formed by continued sulfur loss and accumulation of excess iron atoms that lead to the growth of metallic nuclei on the sulfide surfaces. Thermal stress induced by thermal cycling could also have contributed to the whisker growth.

The sulfur loss by the space weathering of iron sulfides may contribute to sulfur depletion detected on the surface of S-type asteroid Eros [9]. Furthermore, the sulfur loss from iron sulfides likely causes mass-dependent fractionation of sulfur in regolith grains and supports the notion that the enrichment of heavy sulfur isotopes in mature lunar soils is due to sulfur loss by space weathering [e.g., 10]. Thus, iron sulfides are highly susceptible to decomposition by space weathering, which may change the chemical properties of regolith. The general similarities of space weathering of iron sulfides between the Moon and Itokawa indicate that the alteration of iron sulfides is common among airless bodies in the solar system.

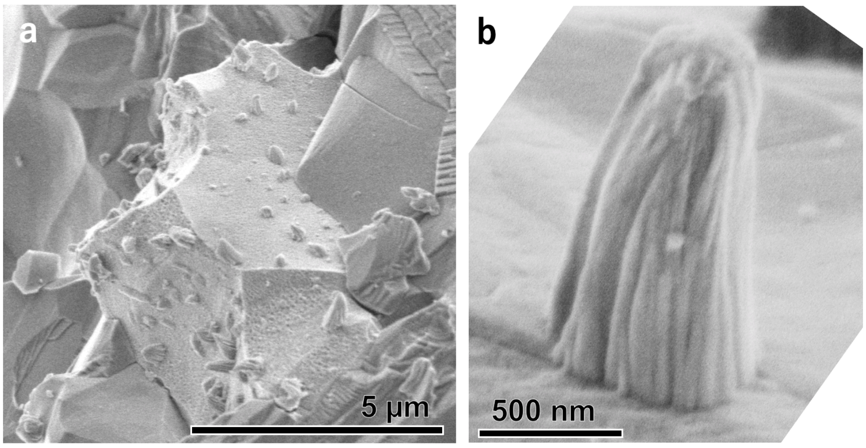

Fig.1 . Secondary electron images of whiskers on iron sulfide surfaces. (a) Iron sulfide grain on an Itokawa particle. Numerous whiskers appear on the sulfide. (b) Enlarged image of an iron whisker on a sulfide surface of an Itokawa particle.

References:

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