SPACE WEATHERING OF IRON SULFIDE GRAINS FROM ASTEROID 25143 ITOKAWA .

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Introduction: Iron sulfides are ubiquitous in chondritic meteorites and cometary samples. Although iron and sulfur are major solid-forming elements in the early solar system materials, their presence in presolar environments is poorly understood. One of the proposed alteration processes of iron sulfides in the interstellar environment is the destruction of solid iron sulfide by irradiation of ions accelerated by supernova shocks [1]. On the other hand, iron sulfides are also expected to be altered on the surface of S-type asteroids by solar wind irradiation and micrometeorite bombardments, causing depletion of sulfur abundance on the asteroid [2]. The modification processes of materials exposed to the space environment are known as space weathering. Understanding the behavior of iron sulfide under space weathering effects will provide a clue to reveal the evolution of iron sulfide and its relation to the life cycle of iron and sulfur in the galaxy. Regolith particles recovered from S-type asteroid Itokawa preserve various space weathering features [e.g., 3-8]. However, little is known about space weathering of iron sulfide relative to silicate minerals. In this study, we investigated surface microstructures on iron sulfide of Itokawa particles in order to evaluate space weathering effects of iron sulfide.

Experiments: Surface features of eleven Itokawa particles were observed focusing on troilite (FeS) using a field-emission scanning electron microscope (SEM: Hitachi SU6600). Three particles were investigated for further study. Regions of interest of the three particles were selected based on the SEM observation. We picked up sections from the selected areas and thinned the sections to the electron transparency using a focused ion beam (FIB: FEI Quanta 200 3DS, FEI Quanta3D FEG).The electron transparent sections were studied by a field-emission transmission electron microscope (FE-TEM: Tecnai G^2 FEG, JEOL 2100F).

Results: From SEM observation of Itokawa particles, submicron sized craters and blisters, which are evidences of micrometeorite bombardment and solar wind implantation [3], were often recognized on troilite as well as silicate surfaces. Some troilite surfaces display whisker-like structures ranging from several tens of nm to 2 μm in length. We lifted out FIB sections from troilite surfaces where the whiskers develop on its surface. TEM analysis shows that polycrystalline layers with many vesicles were developed beneath the troilite surface extending from 70 nm to 90 nm in depth. Whiksers are located on the uppermost surface of the vesicular rim. Electron diffraction patterns revealed that the whiskers have a structure of body-centered cubic iron. Small whiskers mainly consist of a single crystal, while larger whiskers are composed of a bunch of several whiskers. The vesicular rim with whiskers are coated with a thin layer including O, Mg, and Si, possibly corresponding to vapor deposited materials. Olivine and pyroxene grains in the vicinity of the troilite have solar flare tracks of approximately 10^8 /cm^2 to 10^9 /cm^2. These values are in the range of previously reported densities in other Itokawa particles [e.g., 3,4,5,7].

Discussion: The vesicular rims have been observed in space weathered rims of silicate grains [3] and considered to be formed by hydrogen and helium gases after the accumulation of solar wind hydrogen ions and helium ions. The vesicles in troilite might have developed in the same process. On the other hand, iron whiskers have not been reported on silicate grains of Itokawa particles. They could have been produced through iron excess by selective sputtering of sulfur atoms by solar wind irradiation [9] and/or by reduction of iron sulfide by solar wind hydrogen resulting in the production of Fe metal and the evaporation of H_2S [10]. The stress relief mechanism reported for metal whiskers on electronic devices, such as Ag whiskers on Ag_2S [11], is also a possible process for iron whisker growth. We estimated characteristic diffusion distance of iron atoms in iron sulfide using diffusion coefficient of pyrrhotite [12]. The diffusion distance reaches 1μm for approximately ten years under radiative equilibrium temperature at Itokawa's perihelion (400K). Although troilite might have a lower diffusion coefficient of iron atoms than that of pyrrhotite due to a lack of inherent vacancies, defects in troilite induced by solar wind irradiation could enhance diffusion of iron atoms. Alternatively, orbital perturbations may have brought Itokawa closer to the Sun in the past, leading to higher surface temperatures and faster diffusion [5]. Therefore, iron atoms could sufficiently diffuse from troilite into iron whiskers during the short stay of regolith particles on Itokawa's surface.

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