MICROSTRUCTURAL AND CHEMICAL ANALYSIS OF SOILS FROM ITOKAWA: EVIDENCE FOR SPACE WEATHERING

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Introduction: The morphology, microstructure, and chemistry of grains on the surfaces of airless bodies can be altered due to interactions with solar wind, galactic and cosmic rays, and micrometeorite impacts. Together these processes are identified as space weathering and they directly influence the surface properties of airless bodies which we measure through remote sensing. Space weathering darkens and reddens the reflectance spectra of these objects, an effect which is attributed primarily to the production and deposition of nanophase iron (npFe^0) onto the rims of soil particles, and also attenuates absorption bands [1-2]. The alteration of surface properties by space weathering has led to a discrepancy between remotely sensed spectra from asteroids and those acquired directly from meteorites [3]. This inconsistency has made it difficult to correlate samples of meteorites with their parent bodies in the asteroid belt.

Obtaining ground-truth data for studies in space weathering has historically been limited to lunar soils and select asteroidal and lunar regolith brecciated meteorites [4-6]. However, with the return of samples from near-Earth asteroid Itokawa [7], the Hayabusa mission has provided a second data point for studying space-weathering effects on planetary surface materials. Analysis of this asteroidal material and comparison with lunar soils should improve our understanding of space weathering and permit a comprehensive model for this phenomenon as it varies across different airless bodies. Here we report initial results on microstructural analyses of assemblages from Itokawa.

Samples and Methods: The Itokawa grains analyzed in this study include assemblages from sample RA-QD02-0042-02, an ultra-microtomed transmission electron microscope (TEM) section prepared by the Hayabusa mission sample curator from a particle originally measuring just over 96 µm in width. A selection of the grains in these sections were previously analyzed for space weathering characteristics [8].

We analyzed the microtome slices using a 200 keV JEOL 2010F TEM at Arizona State University. The assemblages were imaged in both conventional (parallel illumination) bright-field and dark-field scanning TEM (STEM) modes. Grain compositions were measured using a thin-window EDAX energy-dispersive X-ray spectrometer (EDS). Selected area electron diffraction (SAED) was used to determine crystal structure.

Results: The primary assemblage analyzed in this study is shown in Figure 1. Bright-field imaging reveals an assemblage composed of multiple distinct grains. The assemblage contains lath-like grains that are separated in some areas by void space. This morphology is characteristic of chattering, an artifact produced during microtome sample preparation and, in this respect, similar to samples observed from the STARDUST mission [9]. EDS chemical mapping (Fig. 2) shows that the bulk of the assemblage contains Si, O, Mg and Fe. Measurement of SAED patterns are consistent with low-Ca pyroxene, as evidenced by multiple diffraction patterns (e.g., Fig. 1, inset). In addition, a grain of crystalline troilite measuring over 500 nm is embedded within this pyroxene assemblage, as identified in Figure 2 and is imaged in further detail in Figure 3.

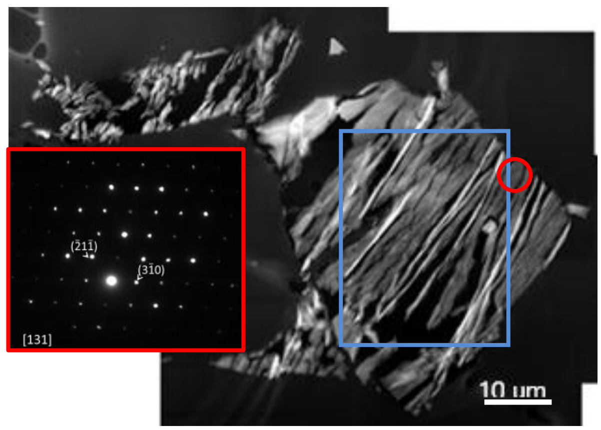

Figure 1: *HAADF STEM image of the assemblage. Red annotation indicates the region where the SAED pattern (inset) was acquired. The blue region was mapped chemically as seen in Figure 2***.**

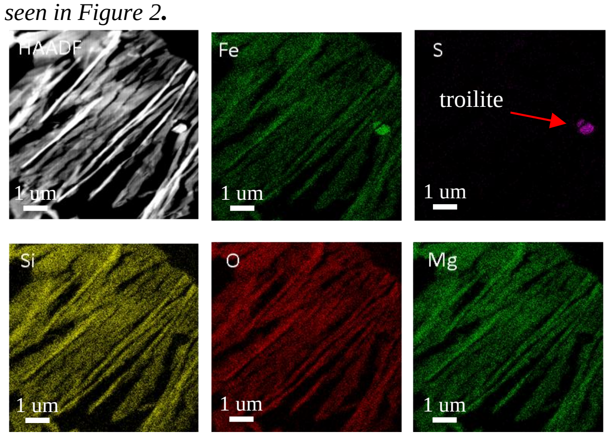

Figure 2: *EDX maps of the assemblage showing element distributions. Identified here is the troilite grain within the low-Ca pyroxene.*

The outer 500 nm of the assemblage contains a discontinuous rim with varied degrees of amorphization. In each region that contains disrupted structure, there is a completely amorphous outer rim of relatively constant (≤15 nm) thickness. Penetrating deeper into the sample is a domain measuring 20 to 80 nm thick that contains isolated sections of completely amorphous material interspersed with crystalline regions (Fig. 3).

Within the amorphous region, there are localized areas that contain possible npFe^0 grains (e.g., Fig. 3). The npFe^0 grains are disseminated and appear to be preferentially concentrated in the zone of partial amorphization. The grains are <5 nm in size and are disseminated throughout these regions. Localized chemical mapping of the rim region did not identify any distinct zones of elemental enrichment or depletion within the amorphous rim structure of this assemblage.

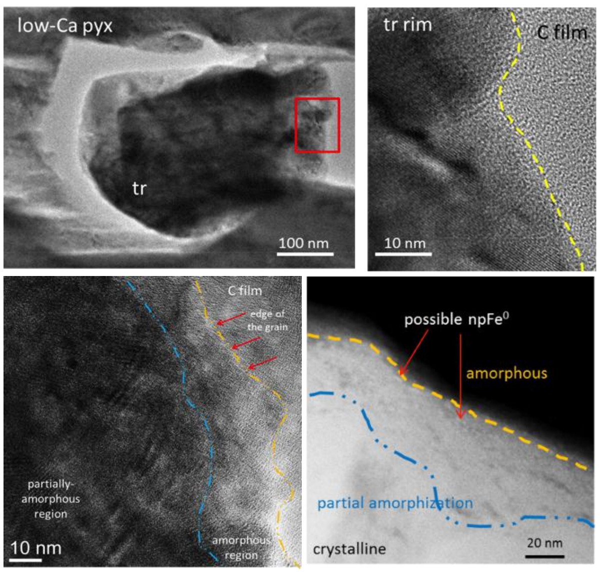

Figure 3: *Top panel: Bright-field TEM images of the troilite grain (left) showing its spatial relationship to the low-Ca pyx and its rim (right). Bottom panel (left): HRTEM image a region of the rim, displaying varying degrees and depths of amorphization. Bottom panel (right): HAADF image of the amorphous rim showing nanoscale grains/particles with relatively higher Z contrast in the partially amorphous zone.*

Discussion: The chemical and structural evidence for space weathering in these Itokawa grains differs from that observed in lunar soils. In particular, the multi-layer structure of these amorphous rims and the deeper zone of incomplete amorphization on each rim are not frequently observed in lunar soils. Such differences may suggest that weathering processes occurring on asteroidal surfaces differ from those governing the evolution of the lunar surface. A possible explanation for this discrepancy is a difference in the surface exposure time for materials on the Moon vs. Itokawa. Lunar soil grains may remain undisturbed on the surface for extended periods, allowing high-energy particles to completely amorphize material up to a maximum penetration depth. While this timescale is yet poorly constrained, the surface of Itokawa must have undergone high frequency mixing/stirring events to prevent this saturation of amorphization. These resurfacing events could be triggered by gravitational interactions with planets or high energy surface impacts [10].

In addition, when compared to the lunar soil we see a significant decrease in the concentration of npFe^0 in the grain rims, particularly in the outer completely amorphized region. The npFe^0 grains in this outer region are theorized to have formed through micrometeorite bombardment and the subsequent vapor recondensation of volatile chemical phases onto the exteriors of adjacent grains [8]. The significantly lower concentration of nanoparticles in this assemblage as compared to lunar soils could suggest that micrometeorite impacts occur at a decreased rate on the surfaces of small bodies in comparison with the Moon, or that the energy of these impacts is significantly lower. This may offer clues as to the dynamical history of Itokawa. Examination of additional assemblages and lunar soils should help test this hypothesis.

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