SPACE-WEATHERING FEATURES ON TWO HAYABUSA PARTICLES R. C. Ogliore[1] and E. Dobrică[2], [1]Hawai'i Institute of Geophysics and Planetology, University of Hawai'i at Mānoa, Honolulu, HI 96822, USA (ogliore@higp.hawaii.edu), [2]Department of Earth and Planetary Sciences, University of New Mexico, Albuquerque, NM 87131, USA.

Introduction

JAXA's Hayabusa mission collected surface regolith samples from the S-type asteroid Itokawa and returned them to Earth for laboratory study. These particles show signatures of space weathering (changes in the optical and physical properties of the surface of an airless planetary body) through micrometeorite impact and energetic-particle irradiation. Microcraters, shock lamellae, and splash features that were formed by micrometeorite collisions can be found on the surfaces of regolith grains from Itokawa, although previous studies (e.g. [1]) found that they are rare compared to lunar regolith. Solar-wind produced nanophase Fe and radiation-damaged rims on the surfaces of Itokawa grains imply that space weathering due to solar wind irradiation is significant [2]. Small circular surface features or "blisters" on Itokawa grains provide evidence of solar-wind irradiation [3] on timescales of hundreds to tens of thousands of years (e.g. [4]). The low surface gravity of asteroid Itokawa ($\sim 10^{-4}$ m/s^2, [5]) compared to the Moon (1.6 m/s^2) may cause micrometeorite impact residue to be distributed over a larger area. Evidence for this effect on the surfaces of Itokawa grains could include: 1) very thin splash melt residue, 2) impact-ejected grains from the target (Itokawa) that traveled far from the impact site, and 3) efficient regolith gardening (from impacts and electrostatics).

We analyzed the surfaces of two Itokawa grains to investigate the nature of solar-wind blisters, splash-melt residues, and small adhering grains.

Methods

We analyzed two Itokawa particles: RB-DQ04-0062 (which we named "Naoko") and RB-DQ04-0091 ("Mizuki"). Both particles were irregularly shaped, with a long dimension of ~ 40 μm, and were composed mainly of olivine and plagioclase (as determined by initial SEM-EDS measurements). We transferred both particles from their JAXA shipping containers to an aluminum SEM stub coated in Post-It note glue using a Sutter micromanipulator and tungsten needle. A thin coat of carbon (~ 5 nm) was applied for conductivity.

Traditional secondary electron microscopy, even using a low accelerating voltage, has difficulty resolving very small and shallow features. The Zeiss Helium Ion Microscope (HIM) at Pacific Northwest National Laboratory uses a primary He^+ beam (30 keV) to generate secondary electrons at the sample's surface without a contribution from backscattered electrons. This microscope has a very large depth of field, small beam size (<0.1 nm), excellent spatial resolution (<0.4 nm), and extreme surface sensitivity, making it ideally suited for imaging small, shallow surface features.

Adhering surface grains were prepared for TEM analysis using the focused ion beam (FIB) technique with a FEI Quanta 3D Dualbeam FIB instrument at the University of New Mexico. Bright and dark-field TEM images and quantitative EDS X-ray analyses were carried out at 200 kV on UNM's JEOL 2010F FEG TEM/Scanning TEM (STEM).

Results

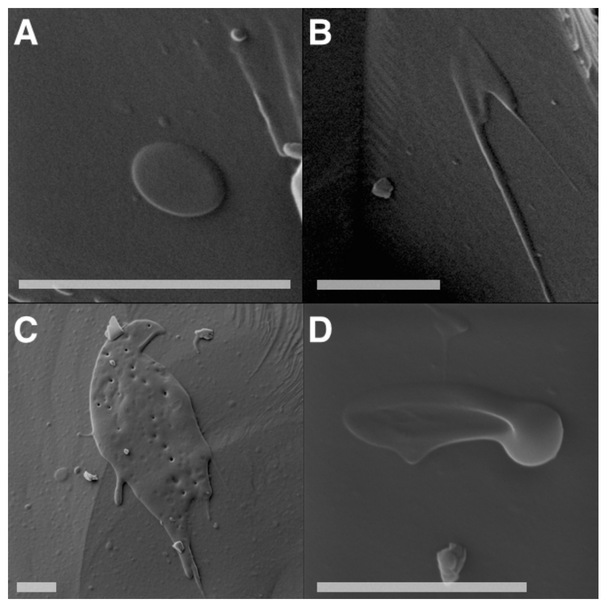

Figure 1: HIM secondary electron images of splash melt features on two Itokawa particles. B and C are from Naoko, A and D are from Mizuki. Scale bars are 1 μm.

Splash melt residue: We observed splash residue on both Itokawa particles. Large splashes (several μm wide and ~ 200 nm thick) were clearly visible on both particles (Figure 1-C). Thin, smaller splash features (Figure 1-B) were common but heterogeneously distributed, as were pancake (Figure 1-A) and droplet melt feautres (Figure 1-D) smaller than 1 μm.

We extracted a thin section from the large splash melt feature on Naoko (Figure 1-C) by FIB for TEM analysis. The splash melt was vesiculated and amorphous, and had variable elemental composition. The adhering grain on the splash melt (Figure 1-C, top) is amorphous and Ca- and Al-rich. The underlying large grain is Fa_{25} olivine. The splash melt varies in chemical composition between Fa_{25} and the composition of the adhering Ca-, Al-rich adhering grain. We propose that a micrometeorite impacted Itokawa and hit a Ca-, Al-rich silicate (e.g. anorthite) and launched liquid melt >40 μm away (possibly much farther) where it splashed onto this Fa_{25} grain. The top layer of the Fa_{25} melted and the whole area quenched, forming this feature.

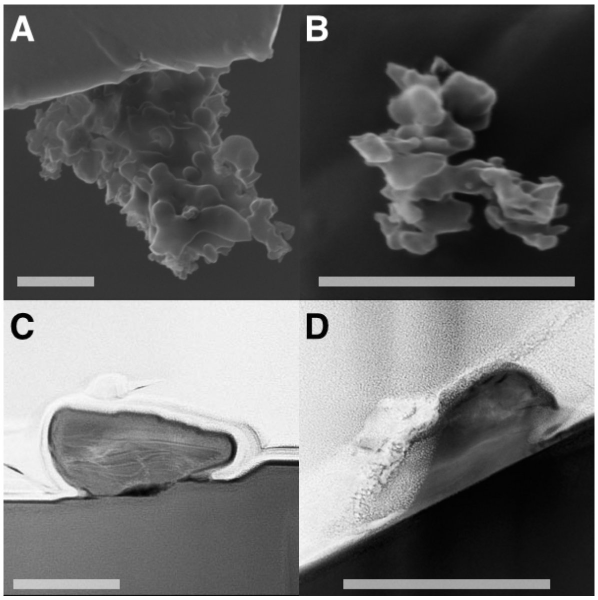

Figure 2: A (Mizuki) & B (Naoko): HIM secondary electron images of two agglutinate-like adhering particles. C & D (both Naoko): Dark-field TEM images of two adhering particles. Scale bars are 0.5 μm.

Adhering grains: The surfaces of both Itokawa grains were decorated with adhering grains, most less than 1 μm in size. We tried removing one with a tungsten needle in the FIB, but the needle bent when pushed into the grain, implying the grain was strongly attached. We removed two grains with agglutinate-like textures (Figure 2-A and 2-B) by FIB and analyzed them by TEM. They were found to be amorphous SiO_2, with the smaller grain on Naoko enriched in Fe and Mg closer to the contact with the underlying Fa_{25}. We propose that these two grains formed during a micrometeorite impact; the smaller grain landed on its host grain while still partially molten. Other adhering grains, such as the chromite with 8.5 wt. % Al_2O_3 shown in Figure 2-D, have no discernible gap between the grain and the underlying mineral and are consistent with the mineralogy of LL chondrites. These grains are lithic fragments, and are obviously firmly attached. The grain shown in Figure 2-D is olivine with a similar chemical composition as the underlying mineral (Fa_{25}) but there is a discernible gap. Also, this grain shows obvious shock features, implying it was excavated during a micrometeorite impact from a surface with similar mineralogy, possibly nearby. However, we did not see any clear impact craters on either Mizuki or Naoko.

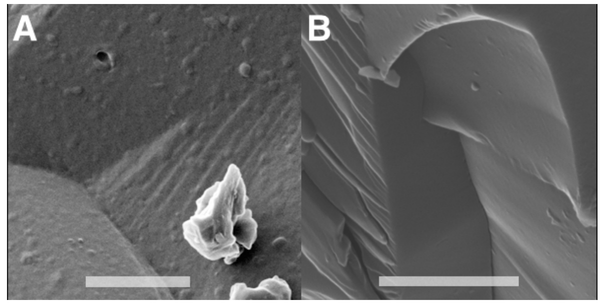

Figure 3: HIM secondary electron images of a SW-blistered surface on Naoko (A) and a non-blistered surface on Mizuki (B). Scale bars are 1 μm.

Blisters: We saw severe blistering on some faces (Figure 3-A), and moderate blistering or no blistering at all (Figure 3-B) on others. A highly blistered area could be found very close to a non-blistered area. We saw blistering covering areas of a conchoidal fracture (Figure 3-A), implying that area was exposed to the solar wind for thousands of years after the fracture. In highly blistered areas, we occasionally saw open/burst blisters (Figure 3-A). The variability in blistering on these particles implies that Itokawa regolith grains fractured on the timescale of blister formation, which is thousands of years.

Conclusions

Our observations show that both micrometeorite impacts and solar wind irradiation modify the surfaces of Itokawa regolith grains. Splash-melt features, agglutinate-like adhering particles, and shocked grains all provide evidence that the surfaces of Itokawa particles were modified by micrometeorite impacts. These features differ significantly from analogous features in lunar regolith samples, likely due to Itokawa's smaller size and lower gravity. Blistering due to solar wind irradiation is both widespread and variable on small spatial scales.

References: [1] E. Nakamura, et al. (2012) *P Natl Acad Sci* 109(11):E624. [2] T. Noguchi, et al. (2014) *Meteorit Planet Sci* 49(2):188. [3] T. Matsumoto, et al. (2014) *Meteorit Planet Sci Supp* 77:5130. [4] S. Assonov, et al. (1998) in *29th LPSC* #1635. [5] N. Hirata, et al. (2009) *Icarus* 200:486.