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Space weathering of Itokawa, a small rubble pile asteroid

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Abstract

Itokawa's surface show darkening and reddening by space weathering, although its surface is covered with rocks and pebbles and deficient in fine regolith. Experimental results suggest rocky meteorite fragments can be weathered. The opposition effect in rocky terrain of Itokawa suggested that the surface would be covered by particulate materials or porous enough to scatter light. Itokawa-derived fine grains (some of which have nanophase iron) in Hayabusa sample capsule clearly indicate the presence of fine particles on the surface of Itokawa and their effect on the optical property of the asteroid.

1. Introduction

S-type asteroids exhibit more overall depletion and reddening of spectra, and more weakening of absorption bands than ordinary chondrites. These spectral mismatches are explained by the so-called "space weathering". One proven mechanism of such spectral change is production of nanophase metallic iron particles [1], which were confirmed in the rim of lunar soil grains [2]. High-velocity dust particle impacts as well as sputtering by solar wind would be responsible for the production of nano-iron particles. We reproduced the spectral change expected in space weathering, using nano-second pulse laser irradiation simulating high-velocity dust impacts [3,4]. We confirmed the formation of nanophase iron particles within the vapor-deposited rim [5]. We considered regolith-like surface condition is essential for the space weathering. When the surface consists of particulate materials, evaporated materials may condense on the surfaces of other particles to form amorphous rim containing nano-iron. This is compatible withsize dependent transition from Q-type (ordinary chondrite-like) objects to S-type objects around the size range 0.1 to 5km [6]. Presence of regolith should enhance the space weathering, and regolith is scarce (abundant) on objects smaller (larger) than the transition size.

2. Itokawa by Hayabusa

In 2005, Hayabusa rendezvoused the S-type asteroid (25143) Itokawa (550m) and performed a color imaging by onboard camera [7]. Almost 80% of Itokawa's surface is rough and boulder-rich but it has a somewhat weathered spectrum on average. Optically, the surface of Itokawa is divided into brighter (and bluer) areas and darker (and redder) areas [8,9]. In rough zones, dark boulder-rich surfaces usually superpose on bright materials. We can interpret that removal of dark space-weathered boulder-rich surface materials by shaking caused by impacts or planetary encounters should lead to exposure of underlying fresh bright area [10]. High-resolution images indicate that boulders are firmly covered with weathered fine particles or boulders' surface are optically weathered (Fig. 1). Bright speckles on dark boulders are probably remnants of micrometeoroid impact, by which fresh interiors unaffected by space weathering are exposed [11].

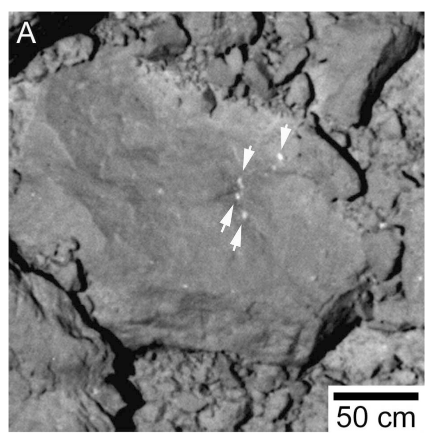

Fig. 1 A weathered angular boulder on Itokawa. White speckles are indicated by arrows [11].

3. Rock weathering

To simulate space weathering, we use a solid-state Nd-YAG pulse laser beam with pulse duration of 6-8 nanoseconds, which is comparable with real dust impacts. We irradiate on meteorites NWA1794 and

Bensour. NWA1794 is an LL5 meteorite found in 2002. Bensour is an LL6 meteorite, which fell on Morocco desert on Feb. 11, 2002. These meteorites were chosen because they are fresh and because spectral observation of Itokawa suggested its similarity with LL5 and LL6 chondrites [9,12] As expected, significant darkening and reddening are observed when a pellet sample was irradiated. Irradiation on a rock sample also resulted in darkening in the visible wavelength range and reddening up to 1500 nm. We have irradiated pulse-laser on several other meteorites and confirmed the spectral darkening/reddening as well as the formation of nanophase iron particles [13].

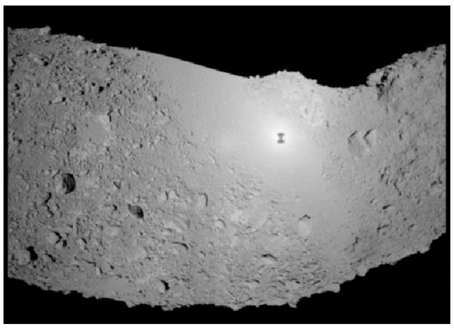

Fig. 2 Opposition effect on Itokawa. The bright area around the shadow of Hayabusa is due to the opposition effect. At the sub-solar point, shadows of rocks, pebbles and grains are hidden beneath then. The absence of shadows causes the brightening.

4. Opposition Effect

The opposition effect (surge) is the brightening of a rough or particulate surface, when illuminated from directly behind the observer. Opposition effect of the airless body surface is considered as a useful tool to investigate the property of the regolith, and in effect, it was observed on the Moon, Mars, regolith-covered asteroids, and icy satellites. As seen in Fig. 2, Itokawa shows the opposition effect. Normally, the opposition effect is observed on particulate or rough surface and it is not expected on the smooth rock surface. Yokota et al. (2006) analyzed the close-up images Itokawa's surface taken by a wide angle camera (ONC-W1) on board Hayabusa [14]. Due to the wide FOV (60 degrees) of the camera, solar phase angle varies widely in one image. Data are taken both from the smooth plain "Muses-Sea" (covered with cm-sized pebbles) and from rocky rough terrain occupying a large part of Itokawa. The rough terrain exhibits opposition surge comparative to that smooth plain. This would prefer the condition that the rock surface would be covered by particulate materials or porous enough to scatter light.

5. Evidence from returned samples

Recent discovery of micron-sized (1-100 micron, typically) grains from Itokawa in the sample container of Hayabusa suggests the presence of fine soil particles. Those particles should coat pebbles and rocks on Itokawa by a very thin layer electrostatically attached). At the touch down of Hayabusa, surface stirring could float the particles. Fortunately a lot of emanated particles were captured in the sample container through the sampling horn.
Microscopic observation shows that some of 10-100 micron sized grains have micron sized very small particles of different mineralogy attached on the surface (Nakamura, E. et al., in preparation). These particles could be produced by granular motion of pebbles on Itokawa's surface or micro-impacts of dust particles on the surface.
Detailed analysis of grains from Itokawa's surfaces by TEM clarified that some of grains are coated with rim containing nanophase FeS and Fe particles (Noguchi, T. et al., in preparation). Amorphous rims have both irradiation and deposition types. This discovery shows that the presence of weathered fine particles on the surface of Itokawa. Those particles would cover surface pebbles and rocks on the asteroid. On the other hand, as was shown by laboratory experiments, rocky surface itself could be darkened with nanophase iron particles if it has some porosity. In either case, the weathered layer should be very thin.

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