Rock space weathering: A lesson from Itokawa and weathering of sub-km asteroids

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Reflectance spectra of S-type asteroids are different from those of ordinary chondrites. These spectral mismatches are explained by the so-called space weathering. S-type asteroids exhibit more overall depletion and reddening of spectra, and more weakening of absorption bands relative to ordinary chondrites. Hapke et al. (1975) proposed the formation of nanophase metallic iron particles in soil coatings from the deposition of ferrous silicate vapor. High-velocity dust impacts as well as sputtering by solar wind would be responsible for vapor formation. We succeeded in reproducing the spectral change expected in space weathering, using nano-second pulse laser irradiation simulating high-velocity dust impacts. We confirmed the formation of nanophase iron particles within the vapor-deposited rim of laser-irradiated olivine grains using TEM (Sasaki et al., 2001).

We considered regolith-like surface condition is essential for the spectral change of space weathering. When the surface consists of particulate materials, evaporated materials may condense on particles to form amorphous rim containing nano-iron particles. The size-dependent transition from Q-type (ordinary chondrite-like) objects to S-type objects occurs around the size range 0.1 to 5km using spectral slopes of near-Earth asteroids obtained through ground-based observations (Binzel et al., 2004). The presence of regolith should enhance the space weathering, and that regolith is scarce (abundant) on objects smaller (larger) than the transition size.

In 2005, HAYABUSA observed an S-type asteroid Itokawa (with size of 550m) by onboard camera AMICA (Saito et al., 2006). Almost 80% of the surface is rough and boulder-rich but it has weathered spectrum on average. Optically, the surface of Itokawa is divided into brighter (and bluer) areas and darker (and redder) areas. In rough zones, dark boulder-rich surfaces usually superpose on bright materials. We can interpret impact-induced seismic shaking or shaking at planetary encounters should remove dark weathered boulder-rich surface to expose underlying relatively fresh bright area (Sasaki et al., 2006). High resolution images indicate that these bouldered surface are optically weathered.

To check the possibility that the rock surface could be weathered, we irradiate pulse laser on meteorite fragments with cut flat surface under vacuum. For comparison, we also irradiate pellet samples where particle size is smaller than 125 microns. Fresh meteorites NWA1794 and Bensour were chosen because spectral observation of Itokawa suggested its similarity with LL5 and LL6 chondrites.

As expected, significant darkening and reddening are observed at irradiating pellet samples. Irradiation on rock samples also resulted in darkening in the visible wavelength range and reddening up to 1500 nm. As for NWA1794 under 15mJ, darkening of the rock sample is 20% at 550 nm, whereas that of the pellet sample is 50%. Rocky meteorite surface is darkened and reddened by weathering simulation, although the weathering degree is weaker than powder-like surface. Ordinary chondrites usually have microscopic porosity with much more surface area than a flat plane. Upon laser irradiation, evaporated material may condense on nearby surface of grains consisting of meteorites. This process would form weathered coating on the rock surface. We consider that the darker boulder-rich zone of Itokawa is made up with dark boulders with weathered coating, which is also suggested from highest resolution image. Small (sub-km) regolith-poor asteroids may also change its brightness and color by space weathering, although their weathering degree would be weaker than regolith-covered asteroids.

References

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