Regolith, Space Weathering, Sulfur

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Introduction: Space weathering is the main process that should control the change of brightness and color of the surface of airless silicate bodies such and the Moon, Mercury and asteroids. S-type asteroids show more overall depletion and reddening of the spectra, and more weakening of absorption bands than ordinary chondrites. These spectral mismatches are explained by the space weathering, where the primary proven mechanism of such spectral change is a production of nanophase metallic iron particles (npFe0) [1], which were confirmed in the amorphous rim of lunar soil grains [2,3]. Vapor-deposition through at high-velocity dust particle impacts as well as implantation of intensive solar wind ions would be responsible for producing the space weathering rims bearing nano-iron particles (npFe0). Simulation experiments using nanosecond pulse laser successfully produced vapor-deposition type npFe0 to change the optical properties [4-5].
Binzel et al. [6] provided a missing link between the Q- and S-type bodies in near-Earth space by showing a reddening of spectral slope in objects from 0.1 to 5 km that corresponded to a transition from Q-type to S-type asteroid spectra, implying that smaller asteroids are fresh or lack in fine regolith, pertaining nano-iron particles.

HAYABUSA-Itokawa: HAYABUSA revealed that small (500m) asteroid Itokawa has weathered surface although its surface is rocky (rough terrain) or pebble-rich (smooth terrain). In 2011, HAYABUSA returned the particulate samples of S-type asteroid Itokawa (more than 1000) back to the Earth. The most notable discoveries in Itokawa particles are amorphous space-weathering rims containing npFe0 [7-9]. A relatively thick (30-60nm) partially amorphous and structurally disordered layer containing abundant 10nm-size npFe0 can be formed by implantation of solar wind (categorized as type-II in ref.7)). Sometimes the layers contain vesicles, probably due mainly to trapping solar wind energetic helium with penetration depth up to a few tens μm (composite vesicular rim [8,9]).
Another type of rim found is a thin (a few to 5 nm) amorphous layer on the outermost surface (categorized as type-I in ref.7). The outermost irradiated rim contains npFe0 with size around 2-3 nm; they are usually observed typically as a monolayer of iron particles. Sulfur and magnesium abundances suggest the presence of nanophase FeS (and MgS). The presence of npFeS in asteroidal regolith is compatible with the observation of regolith breccia meteorites [10].

Sulfur: Previously sulfur would have lost from the airless surface by the processes causing space weathering [11]. Space weathering simulation using a pulsed laser on the Ehole H5 chondrite produced a vapor-deposited coating, which consists of amorphous Mg-rich silicate glass and abundant nanophase (2-5 nm) FeS (npFeS) particles [12]. In our simulation, spectral changes (space weathering reddening and darkening) of olivine samples using pulse laser were facilitated when 5% FeS is added [13]. The addition of pure sulfur particles showed some, but not significant changes.
Both npFeS and npMgS may play an important role on the surface of Mercury in addition to asteroids. On Mercury, MESSENGER revealed a high sulfur abundance (2wt% on average up to 4wt%), which can account for all of Fe by FeS. Spectral feature showed significant darkening/reddening (compared with fresher interior materials), which could not be solely ascribed to compositional difference.

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Keywords: Space weathering, Itokawa, Mercury, sulfur, Moon, regolith

