
The low albedo of the lunar soil, and therefore of the Moon as a whole, has been shown to be linked to an iron-rich substance covering much of the surface of the grains (1). Ground-up rock of similar composition, but lacking the surface film, shows generally a much higher albedo. Since we reported our first results we have analyzed by Auger spectroscopy the surface chemistry of numerous soil and rock samples from all the Apollo missions and found that whereas the concentration of iron on the surface of grains of freshly ground-up rock is within experimental error the same as the bulk concentration, on soil grains the surface iron concentration is in most cases 2 to 3 times greater than the bulk iron concentration (see Fig. 1). The light absorption of the samples is also plotted in this figure, indicating its relationship with the surface iron concentration. This latter relationship is more strikingly demonstrated in Fig. 2. Here, the light absorption column was replaced by a column representing the surface iron concentration required to cause the observed albedo. This concentration was calculated by a least square fit of the albedo (A) and the measured surface iron concentration (n) to the law \( A = A_0 e^{-n} \), which is the law expected for an absorption center density proportioned to the iron concentration. As Fig. 2 indicates the measured iron concentration and the observed albedo fit this law very closely for all iron-rich samples. Indeed this relationship
does not represent the case of the iron-poor, light soil samples where the albedo is dominated by other effects.

Solar wind sputtering and meteoritic evaporation and condensation are the two processes that have been considered capable of causing the coatings on the soil grains. Both are presently being investigated in our laboratory. Hapke (2) demonstrated that rock powders treated by simulated solar wind (2 keV proton or α-particle beams) were darkened to lunar albedo values. Using the same method as Hapke and similar doses of 2 keV energy proton or α irradiation we succeeded (Fig. 3) in demonstrating that the surface iron concentration of ground-up rock samples can be significantly increased by a dose corresponding to a few thousand years of solar wind. The Auger spectrum of irradiated rock powders is strikingly similar to that of soil samples collected from the same site and of similar bulk chemical composition. (The spectrum was obtained in such a way that the analyzing electron beam hits the sample at approximately 60° from the angle of the proton or α irradiation, so that the sputter deposit can be observed.) The albedo of the irradiated rock was also significantly lowered (although not precisely measured in this experiment). As the Auger spectra indicate, there was no carbon contamination caused by this irradiation. The thickness of the iron enriched coatings on lunar soil grains and laboratory irradiated rock grains has not been determined. Auger analysis offers information only to a depth of some 20 Å from the surface. Grant et al. (3) reported that the observed iron peaks in the Auger spectrum of a single grain of an Apollo 17 soil sample disappeared after a short period of argon sputtering, indicating that in this particular case the coating was only a few Ångstroms thick, thus presumably optically insignificant. This was, however, only one experiment on one soil grain. Our Auger spectra are taken of compacted powder samples and represent the average surface composition of many thousands of grains; with such samples, however, the sputtering method cannot be applied to determine the thickness of surface coatings. On the other hand, the laboratory demonstration that solar wind type sputtering is clearly related to both lowering of the albedo...
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and the creation of iron-rich coatings (similar to those observed on samples subjected to lunar weathering) makes the optical significance of the coatings quite clear. The mechanism of the sputtering process is also under investigation. Cassidy and Hapke (4) found that material sputtered off from lunar-like glass by accelerated protons and deposited on a metal substrate was systematically enriched in heavy elements, presumably due to the increasingly greater sticking coefficients with mass. According to their results, provided that the observed coatings on the lunar soil are sputter deposited from material originating from the neighboring grains, the surface should be approximately three times richer in iron, and two times richer in titanium than the bulk. Our results for iron, as indicated above, are in agreement with this observation. We also investigated titanium in the few samples where it was present in significant amounts and found an average enrichment, on the surfaces of soil samples, of 1.9, also in agreement with Cassidy and Hapke's observations.

References