

MODELING THE SPECTRAL EFFECTS OF MICROSCOPIC IRON METAL ON GLASS AND MINERALS; Paul G. Lucey, Hawaii Institute of Geophysics and Planetology, University of Hawaii at Manoa, 2525 Correa Rd., Honolulu HI 96822

The optical effect of soil maturation is a vexing problem in spectral remote sensing of the Moon. This effect--primarily darkening, reddening and loss of spectral contrast--has been studied by a number of workers (1,2,3,4) partly in an effort allow separation of the spectral effects of composition and maturity. Currently, there is a near consensus that much of the spectral changes observed with maturation is due to the presence of extremely fine grained Fe metal in the lunar soil(4). This metal is produced by reduction of divalent Fe to Fe metal by micrometeorite impact heating of soil components rich in solar wind hydrogen. The process has been studied empirically in the laboratory by Allen et al (2) in a series of experiments which dramatically illustrate the influence of fine-grained metal. In these experiments powdered minerals and one glass were reduced by heating in a flow of hydrogen gas. This process produced very fine blebs of Fe metal which partially coated the surfaces of mineral grains. The samples before and after reduction were characterized spectrally and the reduced samples were darker, redder, and exhibited lower spectral contrast than the unreduced samples, characteristics consistent with the optical effects of maturation. The spectra of these samples and their careful documentation were used for the testing of models attempting to account for the spectral effects of maturation assuming that the process carried in the laboratory is representative of that occurring on the lunar surface (data graciously provided by R. Morris). As the optical effect of this fine-grained metal, much of which is sub-wavelength in size, cannot be modeled with geometric optics, other approaches must be sought. An approach using electromagnetic wave theory is pursued below.

Allen et al. observed that the Fe metal grains were often sub-micron in size, and thus subwavelength to near-IR photons, and that the Fe grains coated the sample grains. These observations suggested an initial approach to treat the Fe metal as a continuous thin film coating grains of unaltered starting material. The transmission and reflectance of thin films of Fe were calculated using the complex refractive index of Fe(4) assuming an Fe layer between non-absorbing dielectrics. A model single scattering albedo (SSA) of the reacted material was calculated assuming that radiation would be partially reflected by the Fe coating and the transmitted radiation would interact with the unaltered grain within. The optical properties of the grain inside the coating was modeled using the SSA of the unaltered material calculated from their reflectance spectra (5). The initial reflectance and several internal bounces off the grain and coating were calculated and summed to yield a model SSA for the coated grain. These model SSA's were compared to the SSA's of the reacted samples calculated from their reflectance spectra. The thickness of the coating was adjusted to achieve a best fit. Results are shown in Figure 1.

The two samples with the largest amounts of Fe metal were modeled fairly well with this procedure. The reacted olivine sample was fit very well with a 220 Å film of Fe. Using the volume fraction of Fe in the reacted sample and assuming spherical particles uniformly coated with Fe, 5 micron grains have the proper surface area to volume ratio for 220 Å films to account for all the Fe metal in the reacted olivine sample. While a 5 micron grain size is a trifle small, this is not an unreasonable equivalent grain size for these <75 micron sieved samples. A very Fe-rich glass, with over 8wt% Fe metal in the reacted sample, required only a 70 Å thickness to model the spectral shape (though the mean SSA was not matched well) despite the higher Fe abundance than the reacted olivine. This yields a 0.6 micron equivalent grain size. This seems inconsistent with the olivine measurement. However, Allen et al reported that the reacted glass sample required regrinding and that the devitrified sample was composed of submicron crystals and shot through with Fe blebs. To first order this observed very fine grain size result agrees with the results of the model.

The other samples, all poorer in total Fe and Fe metal than the olivine and glass, could not be modeled well with this approach. In order to roughly match the albedos, extremely thin Fe films were required (the films were so thin that bulk optical constants no longer applied; modified optical constants were calculated using Maxwell Garnett theory (6) which resulted in a blue, rather than a red slope as Fe in transmission is quite blue. The conclusion drawn was that the dimensions

of the Fe blebs produced by reduction behaved optically in a manner equivalent to films with a minimum 220 Å thickness. When abundances dropped below about 3wt%, the coatings then behave optically as discontinuous 220Å films. This was approximated by calculating the SSA of each low-Fe mineral with a continuous 220 Å film, then using an average of the SSA of the model coated material and the SSA of the unreacted material, weighted by the amount of Fe in the reacted sample assuming that 2.8wt% Fe-metal corresponded to a continuous film. The results were much better than using a continuous film. Of the four minerals modeled with the patchy 220Å film, one had a near perfect fit, two showed somewhat redder slopes than the model fits but the same spectral contrast, and one showed higher albedo than the model fit.

The modeling exercise was partially successful and suggests that approaches using the complex index of refraction of Fe as inputs to models based on electromagnetic wave theory may yield results adequate for spectral modeling of maturation.

References: 1)Hapke B. W. Cassidy, and E. Wells, Moon 13 339-353, 1975; 2)Allen C.C., R.V. Morris, H.V. Lauer Jr., and D.S. McKay, Icarus 104, 291-300, 1993; 3)Fischer, E.M. and C. M. Pieters, Icarus 111, 475-488, 1994; 4) Weaver, J.H., Phys. rev. B 19, 3850 (1979); 5) Hapke, B. J. Geophys.. Res.. 86 B4 3039-3054, 1981; 6) Heavens, O.S. Optical Properties of Solid Thin Films, Dover, 1991.

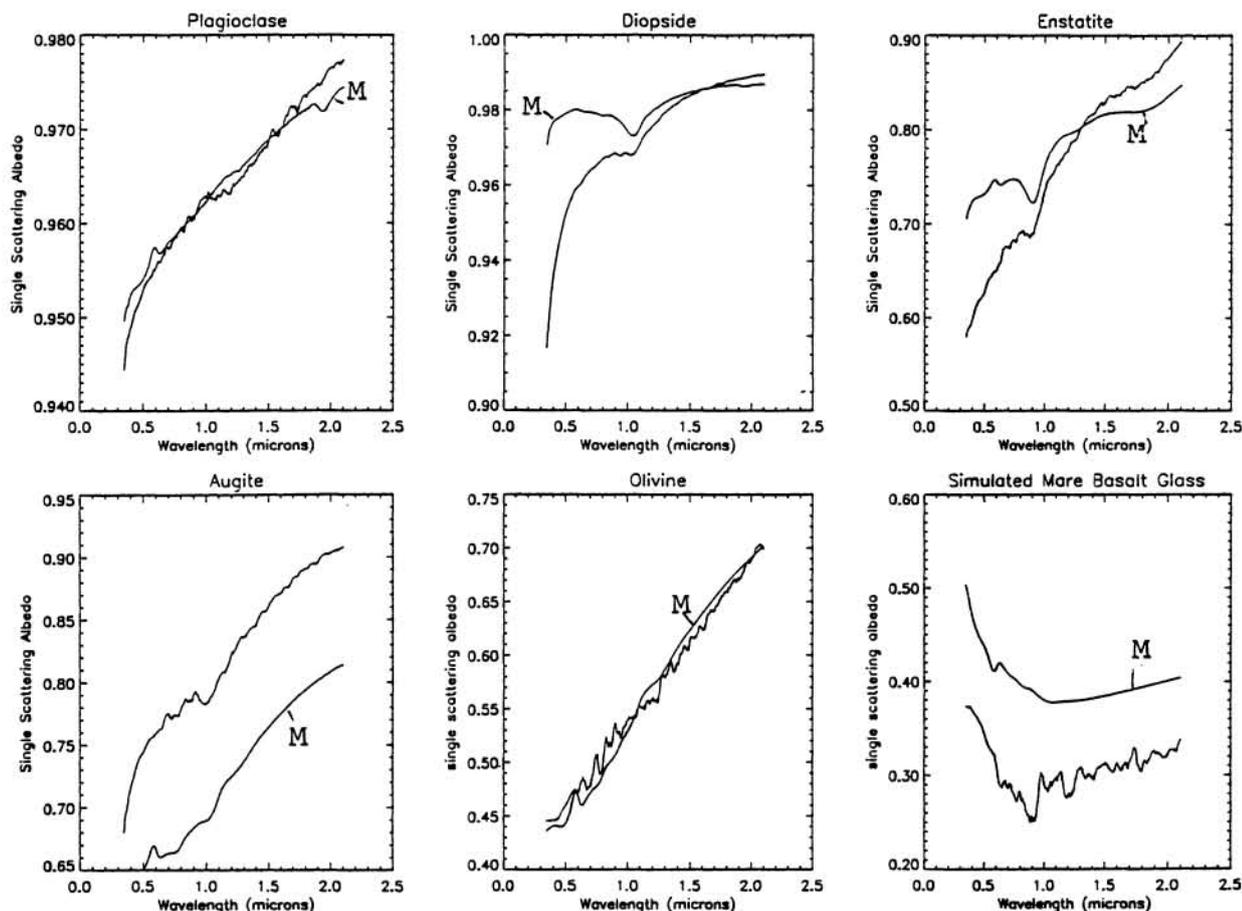


Figure 1. Single scattering albedo spectra of hydrogen-reduced minerals from Allen et al. and model fits using spectra of unaltered starting material and reflectance and transmission properties of thin iron films. "M" indicates model curve.