AN EXPERIMENTAL ANALOG TO MATURING LUNAR SOIL C.C. Allen¹, R.V. Morris² and D.S. McKay², ¹Lockheed Martin, Houston, TX 77258, ²NASA JSC, Houston, TX 77058

Maturation, caused by a combination of processes known as space weathering, changes the optical properties of exposed lunar soil. Changes include darkening, masking of spectral features and increasing the continuum slope. These optical effects have been attributed to increasing concentrations of agglutinitic glass containing nanometer-scale iron metal particles. We have developed an analog material, consisting of 6-nm iron metal particles on a silica gel substrate. Changes in the VIS/NIR reflectance spectrum of this material with changing concentration of iron metal closely approximate the changes induced by natural maturation in lunar soil.

Introduction. We are attempting to duplicate the optical effects of maturation, caused by space weathering, on lunar regolith samples. Our method is subsolidus reduction using hydrogen gas. This work is a direct complement to studies of natural space weathering in lunar soil [1]. We previously studied the optical effects of reduction on terrestrial minerals and lunar simulant glasses [2]. A companion paper at this conference discusses experimental space weathering of 17 lunar soils [3]. Here we describe a simple but potentially very useful analog to iron-bearing agglutinates in the regolith.

Lunar Soil. Agglutinates are individual particles (generally <1mm) that are aggregates of smaller lunar soil particles bonded together by vesicular, flow-banded glass [4]. Agglutinitic glass is formed when micrometeorite impacts melt small volumes of soil containing solar wind hydrogen and carbon. The melt quenches rapidly in a strongly reducing environment and metallic iron particles having nanoscale dimensions are formed by reduction of Fe²⁺. The most mature lunar soil contains ≤1 wt% of these metal particles [5]. Nanophase iron metal is thought to be responsible for the optical effects characteristic of regolith maturation [1].

Optical changes in lunar soils induced by maturation have been quantified by Fischer and Pieters [1]. The soil albedo decreases with increasing maturity. Absolute reflectivity at a wavelength of 0.56 µm has been used as a comparison point. Published values for pristine lunar soils range from 0.38 (immature) to 0.11 (mature). The depths of individual absorption bands below the surrounding continuum decrease as a result of space weathering. The depth of the prominent band centered around 1 µm ranges from 15% (immature soil) to 2% (mature soil). Space weathering of lunar soils produces a red-sloped continuum, i.e. an increase in continuum slope. The slopes bounding the 1 µm absorption band for pristine lunar soils increase from 0.25 to 1.00 reflectance units / 1000 nm with increasing maturity.

Optical Analog. Our analog was prepared from silica gel powders (35-74 µm) whose discrete particles contain 6-nm diameter pores. The powders were impregnated with ferric nitrate solutions of various normality and calcined in air at ~550°C. The result was silica gel in which the pores contained discrete islands of hematite (Fe₂O₃). These gels were extensively characterized by Morris et al. [6] in a study of optical analogs to the soil of Mars.

To produce a lunar soil analog, we reduced the Fe₂O₃ particles to iron metal. Gel samples with various hematite loadings were placed in a 900°C furnace and exposed to flowing hydrogen for 2-6 hours. The temperature was then lowered at 500°C/hr while hydrogen flow was maintained to prevent oxidation of the metal. The samples were removed at furnace temperature between 25-70°C.

Results. The heating experiments resulted in dehydration of the silica gel, with weight losses of 14-20%. XRD spectra showed no evidence of crystallization in the silica. Powders containing no added iron remained white after reduction. The reflectance spectra did not change appreciably, except for decreases in the depths of SiOH and H₂O bands near 1360 and 1890 nm resulting from dehydration (Figure 1).
AN EXPERIMENTAL ANALOG TO MATURING LUNAR SOIL: ALLEN C.C. et al.

We ran experiments on gels with Fe$_2$O$_3$ loadings of zero to 19 wt%. With increasing iron content, the samples darkened to off-white, through grey and finally to jet black. Figure 1 compares the VIS/NIR reflectance spectra of samples with nanophase iron abundances between zero and 1.1 wt%. As iron concentrations increased the reduced samples became considerably darker. Samples with >3 wt% iron had flat spectra with near zero reflectivities.

The silica gel, even after heating, displayed spectral absorption features due to SiOH and H$_2$O. The depths of these features became progressively less with increasing abundances of nanophase iron (Figure 1). This effect may be caused by a combination of optical masking and scavenging of OH by hydrogen.

The spectra of samples with low abundances of nanophase iron metal displayed pronounced red slopes (Figure 1). The sample containing 0.6 wt% metal produced the steepest slope, approximately 0.23 reflectance units / 1000 nm. Samples with iron abundances of 3 wt% and greater were so dark that their continua slopes were essentially zero.

Discussion. Our experiments with lunar soil reduction [3] showed that high concentrations (2-12 wt%) of iron metal blebs, many with diameters larger than 0.1 μm, strongly darkened the samples. Spectral features were effectively masked. These large metal particles did not, however, produce the red sloped continua characteristic of natural maturation. The continua slopes were equal to, or more often lower than, those of the pristine soils.

The current work with nanophase iron particles in silica gel more faithfully approximates the optical changes characteristic of natural maturation. The samples become progressively darker and the spectral features are more completely masked with increasing metal content. In addition, samples containing 1 wt% nanophase iron or less produce spectra with significant red slopes. The slope for the sample containing 0.6 wt% iron approaches values characteristic of mature lunar soil. A simple transparent material containing <1 wt% nanophase iron particles thus provides a useful analog to study the optical properties of maturing lunar soil.