EFFECTS OF MICROSCOPIC IRON METAL ON THE REFLECTANCE SPECTRA OF GLASS AND MINERALS

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Maturity, which is a measure of the time lunar soils have been in the upper ~1mm of the surface (1), is correlated with changes in the soils' optical properties. Mature soil is darker and somewhat redder than immature soil of the same composition, and features in the reflectance spectrum become more subdued with increasing maturity (2). The maturation process also involves accumulation of agglutinitic glass and submicroscopic metallic iron particles (3). We have produced sub-micrometer iron metal blebs on the surfaces and within glass and mineral grains by the method of high-temperature reduction. This technique has permitted the determination of optical changes in samples much simpler than lunar soil, and offers a useful tool with which to investigate the maturation process.

Experimental. Starting materials included synthetic glass of basaltic composition, pyroxene (enstatite, augite, diopside), olivine (Fo91), and plagioclase (An80). The samples were crushed and sieved to <74 μm. They were then reduced with flowing hydrogen in a vertical tube furnace for 3-4 hours at 1100°C. The oxygen fugacity was held three to four log units below the iron-wustite buffer. Visible and near-infrared (VIS/NIR) reflectance spectra were collected before and after reduction. Samples were also analyzed by iron Mossbauer spectroscopy (FeMS), SEM, and XRD. Complementary results are reported in this volume (4).

Results.

Synthetic Basalt Glass (13 wt% FeO): Heating in hydrogen resulted in complete devitrification as well as partial reduction of Fe²⁺ to iron metal. Devitrification products, in the form of intimately mixed submicrometer crystals, included pyroxene, plagioclase, and cristobalite. The iron metal occurred as rounded blebs 0.3-1 μm across, covering 20-30% of the surfaces of typical grains and distributed through grain interiors. The sample turned from tan to black, and all features of the reflectance spectrum were masked (Figure 1).

Enstatite (10 wt% FeO): FeMS and XRD data indicated that a small portion of the FeO in this sample was reduced. The SEM showed iron blebs approximately 0.1-0.3 μm in size coating 10-30% of some grain surfaces. The powdered sample, originally white, was brown-gray after reaction. The strong VIS/NIR features were almost completely masked, though dips near 900 and 1900 nm remained in the spectrum of the reacted material (Figure 2).

Augite (6 wt% FeO): A limited portion of the ferrous iron in this sample was converted to metal. Rounded iron blebs, 0.2-0.7 μm across, were sparsely scattered across some grains. In no case did these blebs cover more that 10% of a grain surface. No iron blebs were identified in grain interiors. The pale green starting powder was changed to gray during the reaction. Spectral features centered near 800 and 1000 nm were strongly but not completely masked. The continuum of the reacted material spectrum rose toward longer wavelengths.

Diopside (2 wt% FeO): Reduction of this sample yielded only traces of iron metal. The iron peaks in the FeMS and XRD spectra, if present, were below the detection limits. An SEM examination of several reacted grain surfaces disclosed a very small number of 0.5 μm iron metal blebs, covering altogether less than 1% of the surface area. The diopside powder changed from white to pale gray. The reflectance spectrum showed only a partial masking.

Olivine (9 wt% FeO): A substantial part of the FeO in the starting olivine was reduced to iron metal. Iron blebs 0.5-1.5 μm across coated 20-30% of the surface area on all grains examined. Blebs 0.5 μm across were also distributed along parallel planes in the interiors of some grains. The pale green starting powder was changed to black. The reflectance spectrum of the reduced sample was essentially featureless, with reflectivity values ranging from 5-15% and a distinct rise in the continuum toward longer wavelengths. The features which characterized the starting material's spectrum were no longer visible (Figure 3).
Plagioclase (0.4 wt% FeO): Reduction of even the very small amount of FeO in this sample produced detectable effects. Scattered iron blebs, 0.3 um across and smaller, decorated less than 1% of grain surfaces. The abundance of iron was below the XRD detection limit, but small peaks produced by the metal were visible in the FeMS spectrum. The powder, initially white, changed to pale gray. The reflectivity declined from 80% to less than 60% (Fig. 4).

Discussion. A portion of the Fe$^{2+}$ in basaltic glass and minerals can be reduced to metal in a few hours at a temperature of 1100°C and an oxygen fugacity well below the iron-wustite buffer. Part of the iron metal forms rounded submicrometer blebs on the surfaces and in some cases within the grains. A concentration of such blebs equivalent to 20-30% of a grain's surface area can totally dominate the reflectance spectra of basaltic glass, pyroxene, and olivine. Smaller concentrations can strongly affect the spectra of pyroxene and plagioclase.

Iron metal blebs have apparently never been reported on or within silicate minerals in lunar soil. Such blebs are, however, ubiquitous in agglutinitic glass. We believe that the iron need only be in the optical path to change a mineral's reflectance spectrum. Iron blebs in glass surrounding a mineral grain would have the same effect as blebs on or within the grain itself.

The optically opaque iron metal blebs affect the glass and mineral reflectance spectra in three ways: lowering the overall reflectivity, reducing the spectral contrast of absorption features, and producing a continuum with a general rise in reflectivity toward longer wavelengths (red slope). These effects match the optical changes ascribed to the lunar maturation process (2). Our experiments indicate that high-temperature reduction provides a useful tool to study the optical properties of maturing lunar soil.