FERROMAGNETIC RESONANCE SPECTRA OF H_2-REDUCED MINERALS AND GLASSES;

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INTRODUCTION AND BACKGROUND

In an earlier paper [1], we reported that H_2 reduction of basaltic glass, olivine, pyroxene, and plagioclase resulted in the formation of metallic iron, in the darkening and reddening of the reflectance spectra, and the masking of individual spectral features in the visible and near-IR. Such changes in the reflectance spectra of lunar soils are attributed to increasing maturation (i.e., increasing residence time of a soil in the upper ~1 mm of lunar regolith) [2]. Submicroscopic metallic iron particles disseminated in agglutinitic glass are thought to be responsible for the changes in reflectance spectra associated with maturation [2]. This metal is produced by reduction of ferrous iron and is associated with the impact-melt glass formed by micrometeorite impact at the very surface of the Moon [3,4].

As discussed by [5], submicroscopic (or nanophase) metallic iron (np-Fe^0) particles contribute to the relatively narrow resonance (linewidth ΔH = 530-800 G; [6]) observed in the FMR spectra of all lunar soils. The FMR experiment constrains these np-Fe^0 particles to have diameters in the range 4-33 nm [5]. Relative concentrations of np-Fe^0 have been measured for virtually all lunar soils using ferromagnetic resonance (FMR). The relative concentration of np-Fe^0 (I_s) normalized to total iron concentration (I_s/FeO) is used as a maturity index for lunar soils [6]. Absolute concentrations are reported by [7].

We report here FMR spectra for H_2-reduced minerals and glasses that include the samples studied by [1]. The FMR spectra were recorded at room temperature at a nominal frequency of 9.5 GHz. Sample saturation magnetization reported as Fe^0 was measured with a vibrating sample magnetometer.

RESULTS AND DISCUSSION

The FMR spectra are shown in Figure 1. The samples are ordered in increasing linewidth (ΔH = 790 to 5820 G) of the resonance centered near 3300 G. The linewidth expected for chemically-pure, spherical (only crystalline anisotropy energy), non-interacting, nanophase metallic iron particles embedded in a nonmagnetic matrix at room temperature is ~1000 G [8,9]. It is reasonable to attribute the lunar-like resonances having linewidths between 790 and 1250 to np-Fe^0. The FMR spectrum of reduced ilmenite is reasonably attributed to large metallic iron particles. This is consistent with its high concentration of Fe^0 (39 wt. %) and SEM observations of Fe^0 particles in the 1-10 μm range [10]. The samples with np-Fe^0 also contain, to variable extents, coarser-grained metal because their spectra are superpositions of narrow (np-Fe^0) and broad (coarse metal) components. This superposition is most evident in the spectrum for the reduced A11 glass. Reduced diopside has the highest relative proportion of np-Fe^0.

There are several possible reasons for the range in np-Fe^0 linewidths (790-1250 G). The SEM studies of [1,10] show that for Fe^0 particles larger than the detection limit (~0.1 μm), the average particle diameter increases through the samples series in the same order as the np-Fe^0 linewidth. It seem reasonable that np-Fe^0 particles would do the same, and that this is responsible for the linewidth variation. It is also possible that particle-particle interactions also increase through the series because total metal content generally increases with linewidth. Reduction experiments at lower temperatures for shorter times, which would give less reduction and lower diffusion rates for particle growth, might produce np-Fe^0 with smaller linewidths. If only the factors discussed above are important, the intrinsic linewidth for np-Fe^0 should be less than or equal to the lowest value we observe, which was 790 G for reduced diopside. The observation that this value is lower than the theoretical linewidth of ~1000 G implies that other interactions are important. The linewidths observed for lunar soils (530-800 G [6]) are also less than the theoretical value.

References: [1] Allen et al., *Icarus*, **104**, 291, 1993; [2] Adams and McMord, *PLPSC4*, 163, 1973; [3] Housley et al., *PLPSC4*, 2737, 1973; [4] Housley et al., *PLPSC5*, 2623, 1974; [5] Housley et al., *PLPSC7*, 13, 1976; [6] Morris, *PLPSC9*, 2287, 1978; [7] Morris, *PLPSC11*, 1697, 1980; [8] Weeks and Prestel, *PLPSC5*, 2709, 1974; [9] Griscom et al., *J. App. Phys.*, **50**, 2402 1979; [10] Gibson et al., *JGR*, submitted, 1994.

FMR OF H_2-REDUCED MINERALS: Morris R. V., *et al.*