

FERROMAGNETIC RESONANCE OF FINE GRAINED IRON AND MAGNETITE PRECIPITATES IN SIMULATED LUNAR GLASSES: COMPARISON WITH LUNAR SOILS, D. L. Griscom, C. L. Marquardt and E. J. Friebele, Solid State Division, Naval Research Laboratory, Washington, D. C. 20375

In order to better understand the ferromagnetic resonance (FMR) properties of returned lunar soils, FMR spectra have been obtained for two well-characterized simulated lunar glasses containing microscopic and sub-microscopic metallic iron particles and six simulated lunar glasses containing sub-microscopic magnetite-like precipitates. The X-band FMR intensities of these samples were determined by numerical integration methods for the temperature range 5-573°K and comparisons were made with similar data for lunar soils from every Apollo exploration site.

Glasses containing iron. A sample of reduced simulated lunar glass of a composition similar to rock 10017 was provided by R. M. Housley. Housley (private communication) reported observation of iron octahedra $\sim 5\mu\text{m}$ and a total iron content determined by Mössbauer and susceptibility measurements of ~ 0.2 wt %. Multidomain (MD) effects in the FMR spectra of this sample have been described previously [1,2]. The second sample was a glass of a KREEP composition [3] which was reduced in an H_2 -rich hydrogen-oxygen flame for ~ 1 min; the molten droplets were quenched in liquid nitrogen. FMR and electron microscopic evidence [2] has indicated the presence of iron spherules $\sim 0.02 - 0.05\mu\text{m}$ in the latter sample.

Glasses containing "magnetite". A reexamination was made of a synthetic glass of a KREEP composition, previously shown by Mössbauer, x-ray diffraction, magnetic susceptibility, electron microscopy, and microprobe to contain magnetite-like precipitates. [4] Other powdered glasses of KREEP and lunar-uplands compositions were subjected to simulated ash-flow processes involving fluidization by helium gas expanding vertically into a vacuum at ambient temperatures $\sim 750^\circ\text{C}$. [5] As determined by FMR experiments [5], magnetite-like phases were precipitated in these samples by virtue of the presence of small amounts of O_2 and H_2O ($\sim 10^{-4} - 10$ Torr) added to the helium. Water vapor appeared to be more efficacious than O_2 for this process [5].

Results. By securing experimental baselines at each temperature, the total numerical second integrals of the FMR spectra were obtained for the samples containing MD iron. For the lunar samples and synthetic samples containing magnetite, a limited integral (shaded area of Fig. 1) was obtained which excluded most of the MD iron contributions (if any were present). Typical results are plotted in Fig. 2. Both MD iron samples showed nearly linear increases in intensity with increasing temperature. The curve for the sub- μm MD iron particles displayed about 1/3 the slope of the data shown. All magnetite-containing samples exhibited intensity peaks between

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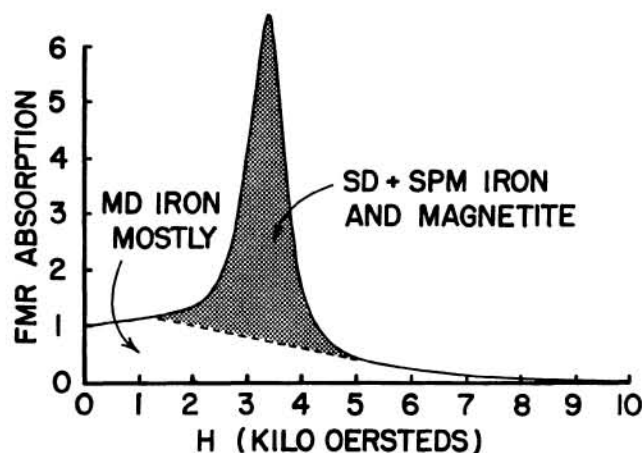
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130 and 230°K; data for a KREEP sample subjected to an ash-flow process are illustrated. The curve for 75081, 70 differs very little from curves obtained for other typical lunar soils [4, 6].

Discussion. Although the literature does not deal adequately with the theory of the temperature dependence of FMR intensity, a good inference is that the intensity should be proportional to the average magnetization of the sample during the field scan [4]. Thus, "theoretically", the intensity of single-domain (SD) iron should vary as the saturation magnetization, M_s . Superparamagnetic (SPM) iron $\geq 60\text{\AA}$ should behave much the same as SD iron in a microwave resonance experiment [7]. The intensity of MD iron will be affected by the microwave skin depth and, for particles $> 1\mu\text{m}$, should increase with increasing temperature much as observed in Fig. 2. The intensity of magnetite should vary as M_s above the Verwey temperature (120°K) but may decrease below that point due to a combination of line broadening and the failure to saturate the sample [4, 5, 6]. If these inferences are correct, the lunar soil data of Fig. 2 are satisfactorily explained by the postulated co-presence of magnetite-like phases [4] along with SD and SPM iron [8].

- [1] D. L. Griscom and C. L. Marquardt, in *The Apollo 15 Lunar Samples*, p. 435 (1972).
- [2] D. L. Griscom, E. J. Friebele, C. L. Marquardt, and D. J. Dunlop, submitted to *Science*.
- [3] Glass GS-64 is described in D. L. Griscom and C. L. Marquardt, *Proc. Third Lunar Sci. Conf.*, *Geochim. Cosmochim. Acta. Suppl.* 3, Vol. 3, 2397 (1972).
- [4] D. L. Griscom, E. J. Friebele, and C. L. Marquardt, *Proc. Fourth Lunar Sci. Conf.*, *Geochim. Cosmochim. Acta.*, Suppl. 4, Vol. 3, (in press).
- [5] C. L. Marquardt and D. L. Griscom, manuscript in preparation.
- [6] D. L. Griscom, E. J. Friebele, and C. L. Marquardt, to be published.
- [7] F.-D. Tsay, S. L. Manatt, D. H. Live, and S. I. Chan, in *Lunar Science-IV*, p. 737, (1973).
- [8] See, D. L. Griscom, C. L. Marquardt, D. W. Forester, and E. J. Friebele in *Lunar Science-V*, (this volume).

Fig. 1. Typical FMR absorption spectrum of a lunar soil. Lunar sample data of Fig. 2 pertain to the shaded area only; (the dashed straight line intersects the experimental curve at 1.25 kOe and 5.25 kOe).



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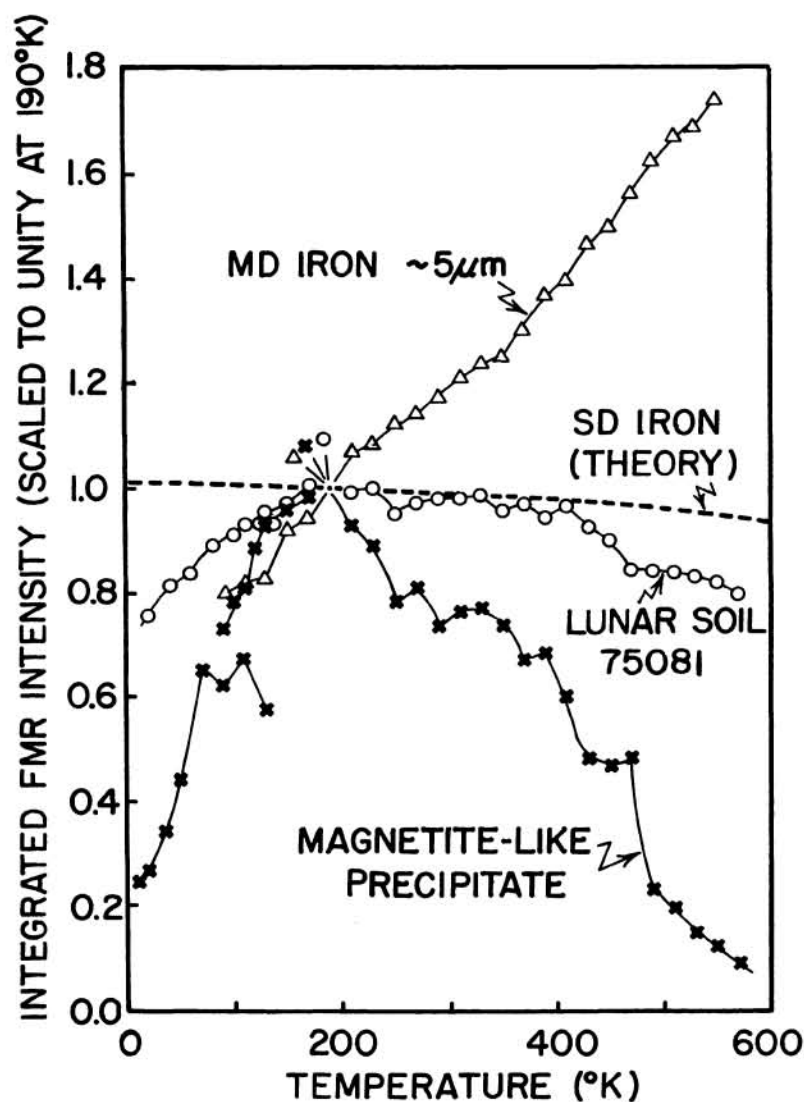


Fig. 2. Integrated FMR intensity versus temperature. Data pertain to MD iron particles $\sim 5\mu\text{m}$ in a simulated lunar glass, submicroscopic magnetite-like precipitates in a simulated lunar glass, and lunar soil 75081, 70. Regions of numerical integration for the latter two samples were deliberately chosen to exclude any contributions of MD iron (see Fig. 1). (Low-temperature data for magnetite-like phases generally do not "connect" with data gathered above 90°K ; similar though less prominent effects are observed for lunar soils.) Dashed curve is the behavior of M_s for metallic iron.