FERROMAGNETIC RESONANCE AS A GEOTHERMOMETER FOR PROBING THE THERMAL HISTORY OF LUNAR SAMPLES,* F. D. Tsay and A. J. Bauman, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103.

The ferromagnetic resonance detected in lunar samples thus far examined has been shown (1,2,3) to consist of two main components with a variety of linewidths, lineshapes and intensities. A narrower component centered at about 3400 G (at X-band frequency) and with a linewidth of 550-1000 G, varying from site to site, is due to metallic Fe which is spherical in shape and in superparamagnetic and single-domain states (Fe^{o}(sp + sd))(3). A broader component extending from zero field to about 10,000 G is due to multidomain and/or non-spherical metallic Fe (Fe^{o}(MD)) (1,2). The narrower component is found to predominate in lunar soils (< 1 mm.) and in low metamorphic grade breccias, in contrast to the broader component found in highly metamorphosed rock samples. A recent annealing experiment carried out on a lunar fines sample has shown that the ratio of Fe^{o} (sp + sd)/Fe^{o} (MD) for a lunar sample decreases with increasing temperature and length of heating (3). This experiment confirms that a correlation which we have previsouly shown to exist between the ferromagnetic resonance spectral features and the metamorphic grade of the sample as defined by Warner (4) is a combined result of grain growth and deformation of sphericity of fine-grained metallic Fe caused by heating. This general correlation can now be used as a built-in geothermometer for probing the thermal history of lunar breccia and rock samples.

Figure 1 shows a number of soils, breccias and rocks and their assigned annealing temperatures, as derived from the ferromagnetic resonance spectra of the metallic iron present. The samples were subjected to no treatment other than ESR examination. The temperatures were assigned by analogy with the behavior of fines 75081,78 which was examined after stepwise annealing in the 600°-1025°C range in the laboratory. The spectral features shown by the various native lunar samples in Fig. 1 appear generally to be due to the formation of multidomain Fe^{o} (MD) from Fe^{o} (sp + sd) during the annealing process.

The spectral changes may be summarized as follows: 1) below 600°C a narrow component at 3400 G with a detectable zero-field component varied with samples; 2) at 600°-700°C the zero-field component increases; 3) between 700°-800°C, accompanied by a broad peak at 6000 G; between 800°-900°C the narrow component diminishes and the 6000 G and zero-field components predominate. Above 1000°C the narrow component at 3400 G is entirely replaced by the broad component extending from zero-field to 6000 G, accompanied by a second peak at 8000 G.

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Table 1 summarizes a classification of some lunar breccia and rock samples on the basis of annealing temperatures, as estimated from their ferromagnetic resonance spectral features.

The nondestructive ferromagnetic resonance method thus appears to provide a route to the rapid classification of lunar samples based on their thermal history as derived from their superparamagnetic, single-domain and multidomain metallic Fe contents.

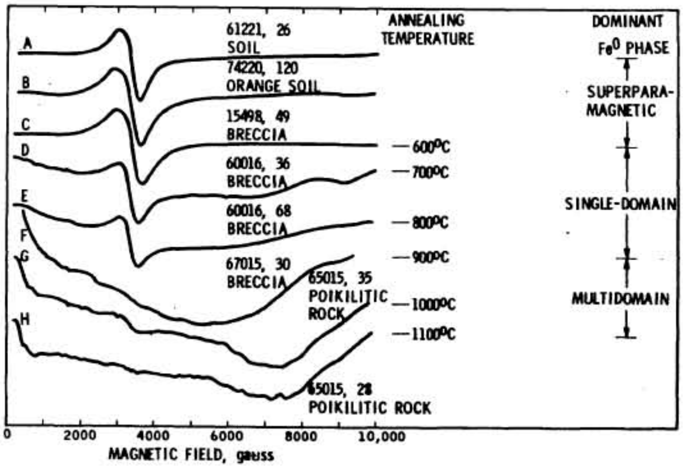

Figure 1. Correlation between ferromagnetic resonance and annealing temperature of lunar metallic Fe phases.

Table 1. Classification of Some Lunar Breccia and Rock Samples According to Their Annealing Temperature of Metallic Fe Phases

Sample	Warner's Grade	Annealing Temperature[c]
15498, 49; 14310, 66	Low[a]	600 - 700°C
60016, 36; 60016, 68 67915, 110; 14318, 36	Medium[a]	700 - 900°C
67015, 30; 15499, 17 14303, 42; 14311, 36	High[a]	900 - 1000°C
65015, 28; 65015, 35 14310, 68	Melt Rock[b]	> 1000°C

a. Defined by Warner (4) for the Apollo 14 breccias.

b. Defined by Warner, et. al. (5).

c. Obtained by comparison of ferromagnetic resonance spectral features with those observed for a fines sample 75081, 78 annealed in the temperature range of 600-1025°C (3). Data for the Apollo 14 samples estimated on the spectra given by Weeks (6).

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