IRON DISTRIBUTIONS AND METALLIC-FERROUS RATIOS FOR APOLLO LUNAR SAMPLES: MÖSSBAUER AND MAGNETIC ANALYSES. G. P. Huffman*, F. C. Schwerer*, R. M. Fisher*, and T. Nagata**. *U. S. Steel Research, Monroeville, Penna. 15146. **National Institute of Polar Research, Tokyo, 173 Japan.

The distribution and valence of iron in lunar material has important consequences for lunar evolutionary models and for lunar physical properties. With specific regard to returned Apollo samples, the chemical state of the iron is related to the occurrence of surface processes such as localized or wide-spread reheating leading to molten-state or subsolidus reduction. The changes in the chemical state of iron that accompany these processes are reflected in several basis physical properties of lunar surface material such as its magnetic remanence and its optical properties.

Metallic-ferrous ratios (Fe°/Fe^{2+}) and the distribution of iron among mineral phases have been determined by Fe^{57} Mössbauer spectroscopy,[1,2] see Table I. The total amount of Fe in silicate phases can be easily determined; however, since the absorption peaks arising from Fe^{2+} in pyroxene, olivine, and glass overlap considerably, the separation of the contributions of each phase is difficult. An approximate method of determining the percentage of Fe in olivine when the percentage is $\gtrsim$5-10% has been described.[1] However, there is still no accurate way of separating spectral contributions of the Fe in glass from that in pyroxene. Therefore, values attributed to pyroxene, Table I, also contain any glass-phase contributions present. (Those samples for which petrographic analysis or large Mössbauer linewidths clearly indicate significant amounts of Fe^{2+} in glass are noted.) The metallic Fe phase, which generally contains small amounts of Ni and/or Co, is not detectable unless it contains at least 0.5 to 1.0% of the total Fe. Consequently, the lower limit for metallic-ferrous ratios is of the order of 0.005 to 0.01. In addition, any metallic Fe which is superparamagnetic at 77°K cannot be detected.

Ferrous-metallic ratios were also determined from laboratory measurements of two room temperature magnetic properties; specifically, the saturation magnetization extrapolated to zero applied field, $I_s(0)$, and the high-field linear susceptibility, χ_a.[3-5] These properties were assumed to be proportional to the amount of metallic (ferromagnetic) iron and noninteracting ferrous (paramagnetic)iron, respectively.[5] The Fe°/Fe^{2+} ratio obtained by magnetic analysis is systematically higher than the Mössbauer result for those samples containing significant amounts of olivine and slightly lower on the average for samples not containing olivine. Liquid helium Mössbauer spectra indicate a stronger interaction between Fe^{2+} spins in olivine than in pyroxence[6] which might explain the former discrepancy if it resulted in a non-linear contribution to the room temperature susceptibility. The latter, somewhat smaller, discrepancy probably arises from fine-grained ($\lesssim$100°A) metallic Fe which behaves superparamagnetically at 300 K and thus contributes to χ_a rather than $I_s(0)$.

APOLLO LUNAR SAMPLES:
MÖSSBAUER AND MAGNETIC ANALYSES

Huffman, G. P. et al.

References

1. F. C. Schwerer, G. P. Huffman, R. M. Fisher and T. Nagata, Proc. Fourth Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 4, Vol. 3, p 3166, (1973).
2. F. C. Schwerer, G. P. Huffman, R. M. Fisher and T. Nagata (1972), Proc. Third Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 3, Vol. 3, p 3173 (1972).
3. T. Nagata, R. M. Fisher, F. C. Schwerer, M. D. Fuller and J. R. Dunn, Proc. Second Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 2, Vol. 3, pp 2641-2476, MIT Press (1971).
4. T. Nagata, R. M. Fisher, F. C. Schwerer, M. D. Fuller and J. R. Dunn, Proc. Third Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 3, Vol. 3, pp 2423-2447, MIT Press (1972).
5. T. Nagata, R. M. Fisher, F. C. Schwerer, M. D. Fuller, and J. R. Dunn, Proc. Fourth Lunar Sci. Conf., Geochim. Cosmochim. Acta Suppl. 4, Vol. 3, pp 3019-3043, Pergamon Press (1973).
6. G. P. Huffman, F. C. Schwerer, and R. M. Fisher, The Apollo 15 Lunar Samples, p 440, Lunar Sci. Inst (1972).

Table I.—Phase Distributions of Fe and Fe°/Fe^{2+} Ratios of Lunar Samples

		Mössbauer Analysis(a)							Magnetic Analysis		
Sample No.	Type(b)	Total in Silicates	Pyroxene	Olivine	Ilmenite	Fe S	Fe°	Fe°/Fe^{2+}	Fe° wt. %	Fe^{2+} wt. %	Fe°/Fe^{2+}
10024	I	56.0	56.0	--	39.0	3.2	1.9	0.019	0.072	15.69	0.0046
10048	B	73.3	73.3*	--	17.7	3.9	5.2	0.055	0.83	19.84	0.042
10084	S	71.0	71.0	--	24.0	∿1.0	4.0	0.042	0.54	16.15	0.034
10085(c)	B								0.20	20.31	0.010
12053	I	92.5	92.5	--	7.5	--	--	--	0.090	15.69	0.0057
12070	S	85.2	85.2	--	7.4	1.9	5.6	0.059	0.59	11.54	0.051
14047(d)	B	84.9	∿78.*	∿7.	3.0	≲1.0	6.0	0.064	0.68	11.08	0.062
14053(e)	I	81.7	81.7	--	6.5	2.0	7.8	0.085	1.21	23.31	0.052
14063	B	82.7	59.6	23.1	17.3	--	--	--	0.016	9.88	0.0016
14259(d)	S	86.0	∿78.*	∿8.	2.0	≲1.0	4.0	0.042	0.69	11.54	0.060
14301	B	90.9	82.	9.	6.0	1.5	1.7	0.017	0.32	9.69	0.033
14303	B	84.2	76.9	7.3	11.3	2.0	2.5	0.026	0.59	11.17	0.053
14311(c)	B								0.34	10.61	0.032
15058	I	98.6	98.6	--	1.4	--	--	--	0.058	16.38	0.0035
15418	B	100.0	59.5	40.4	--	--	--	--	0.067	6.74	0.010
15495	I	98.4	98.4	--	1.6	--	--	--	0.076	17.63	0.0043
15555	I	98.5	77.6	20.9	1.3	--	--	--	0.059	17.63	0.0033
15556	I	96.8	89.1	7.1	2.5	1.3	--	--	0.055	18.74	0.0030
60016	B	89.1	57.8	31.3	2.5	4.0	4.4	0.046	0.34	3.83	0.088
60255	B	93.2	63.9*	29.3	2.9	--	4.0	0.042	0.47	7.94	0.059
60315(c)	I								4.48	14.31	0.31
61156-11	B	92.1	57.9	34.2	2.8	2.8	2.2	0.022	0.70	7.94	0.088
61156-12	B	93.2	49.3	43.9	2.0	1.8	2.9	0.030	1.76	12.97	0.135
66055	B	95.2	37.8	57.4	∿0.5	--	4.3	0.045	0.38	1.85	0.205
66095	I	96.5	51.8	44.7	1.5	--	2.0	0.020	1.22	12.00	0.10
67455	B	98.5	55.8	42.7	1.5	--	--	--	0.021	3.23	0.0066
68415	I	100.0	54.3	45.7	--	--	--	--	0.305	4.52	0.0675
68815(e)	B	91.0	31.3*	59.7	∿1.0	--	7.0	0.075	0.62	6.28	0.099
70017(c)	I								0.097	17.81	0.0054
75083	CF	72.0	72.0	--	26.1	1.4	∿0.5	∿0.005	0.10	15.69	0.0065
77017	I	97.0	64.8	32.2	--	3.0	--	--	0.15	5.08	0.029

(a) Reported as percentages of total Fe. (b) Rock types: B, breccia; I, igneous; S, soil; CF, coarse fines. (c) No Mössbauer analysis presently available. (d) Approx. 6% of the Fe^{2+} is contained in a distinct glass phase.[2] (e) Approx. 2% of the Fe^{2+} is contained in an unidentified magnetic phase, possibly a spinel.[2] *Significant amounts of Fe^{2+} in glass.