SOLAR WIND AND MICROMETEORITE ALTERATION OF THE LUNAR REGOLITH.

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We have recently discussed a model for the formation of fine grained Fe metal in glass welded aggregates during micrometeorite impacts into the solar wind reduced surface of the regolith (1,2). Here we will, 1) elaborate on the reduction mechanism, 2) present new data on Apollo 17 samples and discuss its interpretation in terms of the model, and 3) discuss in terms of the model how magnetic measurements can be used to study regolith dynamics and to define and interpret lunar stratigraphy.

The present intensity of the solar wind is sufficient to saturate mineral grains exposed on the regolith surface with H in at most a few years. We have already discussed data indicating that at least initially a substantial fraction of the escaping H will leave as H_2O, bringing with it O atoms from the regolith (1). In the lunar atmosphere a large fraction of this H_2O will be photoionized (3) within a few months and more than half of that will be swept off the moon by the solar wind while less than half will be reimplanted into the surface (4). Therefore within a few years a layer about 1000Å thick on the outer surface of grains exposed on the top of the lunar regolith will be reduced to the point where the continuing inward and outward flux of H can no longer remove O. Since the gardening rate due to micrometeorite impacts is slow on this time scale, essentially every grain which has been exposed will have outer surfaces as fully reduced as possible by this process.

As a corollary to the above, essentially every micrometeorite will impact fully reduced surface material and hence if Fe containing grains are melted, the glass formed will be expected to contain fine grained Fe metal. We thus see that fine grained ferromagnetic metal (about 0.01-25 μm in diameter) determined by Mössbauer spectroscopy or (about 0.01-1 μm in diameter) determined by ferromagnetic resonance and reduced but isolated Fe° atoms determined by the Mössbauer excess area are both expected to measure the "surface exposure age" of fines samples in the same sense as do glass welded aggregate contents, solar wind rare gas and carbon contents, and fraction of grains with amorphous coatings or solar flare tracks.

All our best Mössbauer data on Apollo fines including remeasurements on old samples and our Apollo 17 results are presented in Table I. The universal inverse correlation of excess area with size fraction is maintained. The increase in excess area in the more magnetic fractions is easily understood since all glass welded aggregates are certain to have been on the very surface at some time. Choosing for uniformity the <45 μm fraction, the ferromagnetic metal content and excess area divided by total Fe content in most cases correlate well with other measures of exposure age.

The fraction of the total Fe in a fines sample in surface layers potentially accessible for solar wind reduction is roughly the specific surface area × thickness × density. Taking respectively 0.33 m^2/g, 1000Å, and 3 g/cm^3 gives 0.1 for this fraction. Since the actual fractions of Fe reduced in different samples (Table I, column 7) are not small compared to this fraction, it seems likely that nearly all the Fe has been reduced in the surfaces which were actually exposed to the solar wind. This in turn suggests the possibility that other cations such as Ti and Si may also have been reduced.

Table I. Zero valent Fe content in Apollo fines samples determined by Mössbauer spectroscopy.

Sample	Size μm	Magnetic fraction	Excess area as wt. % Fe metal	Ferromagnetic metal wt. %	Total Fe wt. %	Excess area / total Fe
12042,38	<45		.184 ± .006	.398 ± .033	7.517 ± .047	.025
14003,22	<45		.352 ± .017	.401 ± .033	6.717 ± .048	.052
14163,52	<45		.277 ± .016	.338 ± .023	6.409 ± .033	.043
15101,92	<45		.212 ± .006	.187 ± .025	4.824 ± .036	.044
15301,85	<45		.259 ± .008	.196 ± .026	6.505 ± .037	.040
61281,8	<45		.196 ± .007	.186 ± .026	3.021 ± .038	.065
	45-75		.098 ± .003	.170 ± .016	2.532 ± .023	.039
	45-75	mag≥1.0	.072 ± .004	.079 ± .022	3.141 ± .031	.023
	45-75	mag≤1.0	.057 ± .005	-	-	-
	75-150		.071 ± .003	.161 ± .015	2.387 ± .021	.030
65701,13	<20		.365 ± .005	.298 ± .022	2.668 ± .032	.137
	<45		.254 ± .007	.242 ± .027	3.223 ± .038	.079
	45-75		-	.231 ± .020	2.867 ± .029	-
	45-75	mag≥4.0	.223 ± .009	.317 ± .028	2.968 ± .040	.075
	45-75	mag≥2.0	.133 ± .006	.174 ± .022	3.069 ± .032	.043
	45-75	mag≥1.0	.053 ± .005	.048 ± .021	3.248 ± .030	.016
	45-75	mag≤1.0	.054 ± .004	.021 ± .018	1.567 ± .026	.034
	75-150		.104 ± .004	.177 ± .020	2.629 ± .029	.040
66031,6	<45		.226 ± .006	.265 ± .030	3.190 ± .043	.071
	45-75		.123 ± .004	.196 ± .014	2.792 ± .020	.044
	45-75	mag≥1.0	.054 ± .005	.010 ± .029	3.189 ± .041	.017
	45-75	mag≤1.0	.041 ± .004	-	-	-
67701,26	<20		.123 ± .006	.057 ± .027	1.927 ± .008	.064
	<45		.114 ± .005	.100 ± .026	2.450 ± .038	.046
	45-75		.055 ± .004	.100 ± .015	2.111 ± .022	.026
	45-75	mag≥1.0	.054 ± .006	-	-	-
	45-75	mag≤1.0	.029 ± .004	-	-	-
	75-150		.033 ± .006	.147 ± .017	2.007 ± .024	.016
Crushed	75-150 to <45		.056 ± .004	.047* ± .015	2.226 ± .015	.025
68501,32	<45		.190 ± .004	.219 ± .022	2.924 ± .032	.065
70051,26	<45		.310 ± .006	.336 ± .033	6.839 ± .047	.045
	45-75		.147 ± .007	.231 ± .028	6.776 ± .041	.022
	75-150		.119 ± .008	.220 ± .028	6.209 ± .041	.019
71501,21	<45		.275 ± .008	.411 ± .031	9.302 ± .044	.030
	45-75		.087 ± .008	.198 ± .031	8.706 ± .045	.010
	75-150		.057 ± .009	.143 ± .039	8.130 ± .055	.007
72141,11	<45		.351 ± .007	.389 ± .034	7.683 ± .048	.046
	45-75		.178 ± .006	.380 ± .041	8.671 ± .059	.021
72501,53	<45		.171 ± .003	.176 ± .021	3.383 ± .030	.051
	45-75		.144 ± .007	.194 ± .026	4.913 ± .038	.029
74220,107	<45		-.067 ± .009	.176 ± .053	10.471 ± .076	-.006
75081,26	<45		.214 ± .009	.343 ± .039	8.076 ± .055	.026

Table I. (Continued)

Sample	Size µm	Magnetic fraction	Excess area as wt. % Fe metal	Ferromagnetic metal wt. %	Total Fe wt. %	Excess area / total Fe
75081.26	45–75		.028 ± .006	.215 ± .023	7.627 ± .033	.004
	45–75	mag⩾2.0	–.004 ± .007	.136 ± .053	8.839 ± .075	–.0005
	75–150		.065 ± .009	.156 ± .044	8.144 ± .063	.008
76501,43	<45		.308 ± .008	.292 ± .032	6.073 ± .047	.051
	45–75		.122 ± .008	.169 ± .040	6.265 ± .058	.019

*Equivalent of .48% Fe metal removed as flakes too large to pass through sieve.

The total Fe contents in Table I determined from the total area in the Mössbauer spectra are of relative significance only. The unknown f factors for all the minerals have been assumed to be 0.80, which is the correct value for Fe metal. In addition saturation corrections which should be applied could raise some of the values as much as 10%. Even with these shortcomings we believe the values listed provide a valid comparison between samples, a comparison which would not otherwise be possible for our size and magnetic separates. They also provide the best possible normalization for our excess area values since they were determined using the same procedures.

The single magnetic domain metal grains produced in lunar fines by surface exposure magnetize easily in small applied fields (5). This makes the low field magnetization of surface fines also a reasonable measure of surface exposure age. We have designed, constructed and tested a simple, portable apparatus for measuring this exposure age profile with high sensitivity and resolution in intact core and drive tube samples. If LSAPT permits, results will be presented and discussed in terms of regolith dynamics.

References

(1) R. M. Housley, R. W. Grant and N. E. Paton (1973) "Origin and Characteristics of Excess Fe Metal in Lunar Glass Welded Aggregates", Geochim. Cosmochim. Acta, Suppl. 4, Vol. 3, pp. 2737-2749.

(2) R. M. Housley, E. H. Cirlin and R. W. Grant (1973) "Characterization of Fines from the Apollo 16 Site", Geochim. Cosmochim. Acta, Suppl. 4, Vol. 3, pp. 2729-2735.

(3) G. R. Cook and B. K. Ching (1965) "Absorption, Photoionization and Fluorescence of Some Gases of Importance in the Study of the Upper Atmosphere", Aerospace Corporation Report No. TDR-469 (9260-01)-4.

(4) R. H. Manka and F. C. Mitchel (1971) "Lunar Atmosphere as a Source of Lunar Surface Elements", Geochim. Cosmochim. Acta, Suppl. 2, Vol. 2, pp. 1717-1728.

(5) R. M. Housley, R. W. Grant and M. Abdel-Gawad (1972) "Study of Excess Fe Metal in Lunar Fines by Magnetic Separation", Geochim. Cosmochim. Acta. Suppl. 3, Vol. 1, pp. 1065-1076.