FINE-GRAINED METAL DISTRIBUTION IN GRAIN-SIZE SEPARATES OF LUNAR SOILS: PRODUCTION AND EVOLUTION OF THE FINE-GRAINED METAL. Richard V. Morris
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Analysis of grain-size separates of lunar soils yields information beyond that obtainable from analyses of bulk soils. Construction of ordinate-intercept plots using rare gas data obtained from grain-size separates permits calculation of the cosmogenic component of the rare gases (e.g., Eberhard et al., 1970). Plots of log C versus log d, where C is the concentration of some species in a grain-size separate of mean diameter d, yields a straight line whose slope is equal to -1.0 if that species is surface correlated; the slope of the straight line equals 0.0 if the species is volume correlated. As an example, the plots of log C versus log d for the solar wind derived gases, such as $^{36}$Ar, should have slopes near -1.0. The values actually measured usually lie between -0.60 and -0.90, which indicates a volume correlated component (e.g., Bogard, 1977). Note that the above criteria for surface or volume correlation are necessary, but not necessary and sufficient conditions for surface or volume correlation; other factors may be involved.

In this abstract are reported the results of analyses of grain-size separates of 94 lunar soils by Ferromagnetic Resonance (FMR). These analyses yield the relative concentration of fine-grained metal (diameter $\lesssim$ 300Å) as a function of soil-particle grain size. Since the fine-grained metal is produced in agglutinative glass during micrometeorite impact at the lunar surface (Housley et al., 1973, 1974, 1975; Morris, 1976), the results of this study contribute to the understanding of regolith processes and evolution.

The relative intensity, $I_s$, or concentration of the fine-grained metal in each grain-size separate was calculated from $I_s = (\Delta H)^2 A/m$, where $\Delta H$ and A are the peak-to-peak linewidth and amplitude of the FMR resonance located at $g$=2.1 and m is the sample mass. The bulk soils (<1 mm) were previously sieved by McKay and coworkers into eight size fractions, the smallest usually <20 μm, by a dry-liquid (freon) method (McKay et al., 1974, and others).

In Figure 1 the values of log($I_s$) are plotted against log(d), where d is the mean grain-size of a grain-size fraction, for a few Apollo 17 soils. The different values of $I_s$ among the soils is due to different FeO contents and/or different periods of surface exposure (Morris, 1976). In order to provide a quantitative representation of the dependence of log($I_s$) on log(d) and because the log($I_s$) versus log(d) data approach a linear relationship, the data for grain-size separates <250 μm in diameter were subjected to a linear least squares fit. The values of the slopes (n) obtained from the linear least squares fit are shown in Figure 2 as a plot of $I_s$/FeO (<250 μm) versus n. The parameter $I_s$/FeO (<250 μm) is a maturity or surface exposure index for lunar soils (Morris, 1976).

With a few exceptions, the data in Figure 2 shows a systematic increase in the value of n from about -0.78 to about -0.18 as the soils mature from immature through submature. The soils denoted by filled symbols contain substantial amounts of orange or green glass and are not expected to follow the general trend. For mature soils, the value of n clusters around -0.18. It can be suggested that the fine-grained metal for the most immature soils is mostly surface correlated (n = -1.0 for surface correlation) and that in the process of maturation the fine-grained metal becomes mostly volume correlated (n = 0.0
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for volume correlation). However, this explanation is probably not viable because analysis of individual soil particles, even in the most immature soils, shows that the fine-grained metal is predominantly associated with agglutinate particles (Housley et al., 1973, 1974, 1975). Housley et al. (1974) has also shown that etching the surface of agglutinate particles does not appreciably alter the values of $I_S$. Thus, it seems most likely that the fine-grained metal resides within the volume of agglutinative glass.

This leaves unresolved the question of why the value of $n$ for many immature soils is near -1.10, i.e., mimics surface correlation. The following two observations can be made: (1) Redistribution of previously-formed agglutinative glass from the grain-size fraction where it was initially formed by such processes as grinding and agglutination to other grain-size fractions is least significant in immature soils since the concentration of agglutinative glass is least in those soils. This argument is not applicable to immature soils that were formed by diluting a mature soil with a very immature soil. (2) Examination of mean grain size data (<1 mm) shows that mixing of lunar soils from the same mission results in soils whose values of $I_S/FeO$ and $n$ are intermediate between the end members; a soil formed by dilution of a soil with measurable maturity by a soil with negligible (unmeasurable) maturity will approximately retain the value of $n$ of the mature soil but will have a reduced value of $I_S/FeO$. Thus, mixing processes apparently cannot produce the soils whose values of $n$ are near -0.78.

Therefore, it is suggested that the values of $n$ around -0.78 are the most primitive and reflect the in situ production of the fine-grained metal as a function of grain size. That is, micrometeorite impact preferentially produces the fine-grained metal in the smallest grain-size fractions.

The increase in the value of $n$ with increasing maturity results because the concentration of fine-grained metal in the larger grain-size fractions is increasing faster than its concentration in the smaller grain-size fractions. The transport of pre-existing fine-grained metal in the smaller grain-size fractions to the larger grain-size fractions through constructional events (e.g., agglutination) is presumably the mechanism by which this takes place. This process cannot continue indefinitely because a point must eventually be reached where the grinding of agglutinative glass in the larger grain-size fractions becomes significant; that is, the transport of pre-existing agglutinative glass to the smaller grain-size fractions becomes significant. The value of $n$ around -0.18 for the mature soils then represents the steady state value for all the processes that produce the fine-grained metal in, and transport it among, the various grain-size fractions.

When correlating the grain-size dependence of $I_S$ with that for such species as $^{36}$Ar and N, the possibility always exists that a bias is introduced due to different methods of sieving. For example, an inefficient separation that leaves fine-grained particles adhering to larger particles will obviously yield misleading results. A bias unquestionably exists between liquid Ar sieving and the dry-liquid (freon) sieving used for the soil analyzed in this study; for example, the dry-liquid sieving yields ~36% of soil 72501 in the <37 µm sieve fraction (Mckay et al., 1974) while liquid Ar sieving yields ~17% of that soil in the same grain size fraction (DesMarais et al., 1975). Therefore, it is questionable whether a meaningful comparison of the results of
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this study can be made with results from grain-size separates produced by liquid Ar sieving.

Figure 3 is a plot of I_s/FeO (<250 μm) versus n for the grain-size dependence of the concentration of ⁴⁰Ar. The solid symbols represent soils for which the I_s and ³⁶Ar data were measured on the same grain-size separates so that no bias due to sieving is introduced. Although the data is somewhat limited, the data in Figure 3 tend to track the data in Figure 2. Namely, the value of n increases with increasing maturity and for mature soil clusters around a constant value which in this case is about -0.62. Thus the data in Figures 2 and 3 enforce the suggestion, based on analyses of agglutinate particles larger than ~90 μm (e.g., Bogard et al., 1974), that the increase in the values of n from ~1.0 to ~0.62 is due to the incorporation of ³⁶Ar into the volume of agglutinative glass during the process of agglutination.

The major findings of this study can be summarized as follows: (1) The value of n from log I_s-log d plots increases from a value of ~0.78 for immature soils to ~0.18 for mature soils. (2) The in situ production of the fine-grained metal is the greatest in the smallest grain-size fraction. (3) Comparison of the values of n for I_s data and n for ³⁶Ar data with increasing maturity provides additional evidence for the incorporation of ³⁶Ar, and presumably other solar wind gases as well, into the volume of agglutinative glass.