

THE NATURE OF AGGLUTINITIC GLASS IN THE FINE-SIZE FRACTION OF LUNAR SOIL 10084.

Lindsay P. Keller¹ and David S. McKay², ¹MVA Inc., 5500 Oakbrook Parkway, Suite 200, Norcross, GA 30093 and ²SN, NASA-JSC, Houston, TX 77058.

Introduction. Agglutinitic glass contains much of the reduced Fe in lunar soils [1], and contributes to the modification of reflectance spectra from lunar soils [2]. Previous work has shown that agglutinitic glass can be compositionally heterogeneous [e.g. 3-5], but the scale of these heterogeneities is not well known. In addition, few data are available on the characteristics of the inclusions in agglutinitic glass. Here we report on our preliminary transmission electron microscope (TEM) examination of agglutinitic glass fragments from the Apollo 11 soil 10084.

Methods. Aliquots of the <20 μm size fraction of 10084 were embedded in low viscosity epoxy and specimens were prepared for electron microscope examination by ultramicrotomy. In the ultramicrotomed thin sections (80- to 100-nm thick), random fragments of agglutinitic glass free of lithic fragments were analyzed using a TEM equipped with an energy-dispersive x-ray (EDX) spectrometer. We analyzed 13 fragments of agglutinitic glass and collected 5 to 10 random analyses from each fragment (97 total analyses) using a probe size of ~ 100 nm. Thin-film EDX analyses were collected so that counting statistics for major elements were $\sim 1\%$; experimental k-factors have relative errors of $<5\%$. The size distribution of submicroscopic Fe metal was determined for each analyzed area.

Results and Discussion. Agglutinitic glass in our samples shows large variations in composition and texture. To assess the heterogeneity within *individual* fragments, we plotted all the analyses from different regions within each fragment in plots of MgO/SiO_2 (wt.%) versus $\text{Al}_2\text{O}_3/\text{SiO}_2$ (wt.%). From these plots, three broad patterns are observed. **Group I.** The smallest group (3 of 13 fragments) random analyses within each fragment are tightly clustered about the composition of the <10 μm fraction of the bulk soil (Fig. 1a). These compositions are highly homogeneous over distances of several micrometers, and the size distribution and number density of Fe inclusions is very similar among fragments of this group. Group 1 fragments represent well-mixed, total melts. **Group II.** This group contains 5 of the 13 fragments and is characterized by linear mixing trends in x-y scatter plots (Fig. 1b). The mixing trends extend between an anorthite-rich component and a mafic component. These melts are not well-mixed. **Group III.** Agglutinitic glass in this group shows strong compositional and textural gradients on a scale of <0.1 μm . The compositional variations are large and are not systematic. In only a few fragments have we identified domains within the agglutinitic glass that correspond to melts of individual minerals (5 regions of anorthite-composition glass and 1 region of augite glass were observed). Textural differences include the presence or absence of vesicles (and the number density of vesicles), the types of opaque inclusions, the size distribution of opaques, and the spatial distribution of opaques.

In agreement with previous studies, the average composition of our agglutinitic glass approaches that of the finest size fraction (Fig. 1e). We have however, observed that S is enriched by a factor of ~ 3 in agglutinitic glass relative to the bulk soil. Similar enrichments in S are observed in vapor-deposited coatings on mineral grains in the same soil [6], and so we believe that the S enrichment observed in agglutinitic glass is the preserved signature of the precursor materials, i.e. fine-grained soil grains with vapor coatings.

Opaque inclusions are typically spherical although most of the larger grains have begun to assume more euhedral shapes, including grains with octahedral faces and cubic forms. The number density of metal inclusions varies significantly among and within individual fragments of agglutinitic glass, however, the size distributions appear similar. Our results show that averaged over all analyzed agglutinitic glass fragments, the sizes of the metal inclusions follow a log-normal distribution (Fig. 1f) with a geometric mean grain size of 6.4 nm (the geometric standard deviation $\sigma_G = 1.81$). The measured size range of Fe grains closely corresponds to the proposed size range for the reduced metal that is known to be responsible for the ferromagnetic resonance (FMR) absorption used to estimate soil maturity [1]. The FMR data suggest a size range of ~ 4 - to 33-nm for the metal grains produced by the exposure-induced reduction of Fe^{2+} [1].

Conclusions. 1) Agglutinitic glass shows compositional and textural heterogeneities at the 0.1 μm scale. 2) The glass fragments preserve a component of vapor deposited material. 3) The number density of Fe inclusions in agglutinitic glass is highly variable, but in general the size distributions tend to be similar and follow a log-normal distribution. 4) The actual size range of Fe grains in agglutinitic glass is similar to that estimated by FMR.

References. [1] Morris, R. V. (1980) *PLPSC* 11, 1697. [2] Pieters, C. M. *et al.* (1993) *JGR* 98, 20817. [3] Hu, H-N and Taylor, L. A. (1978) *Mare Crisium: The View from Luna 24*, 291-302. [4] Walker, R. J. and Papike, J. J. (1981) *PLPSC* 12B, 421. [5] Basu, A. and McKay, D. S. (1985) *JGR* 90, D87. [6] Keller, L. P. and McKay, D. S. (1993) *Science* 261, 1305.

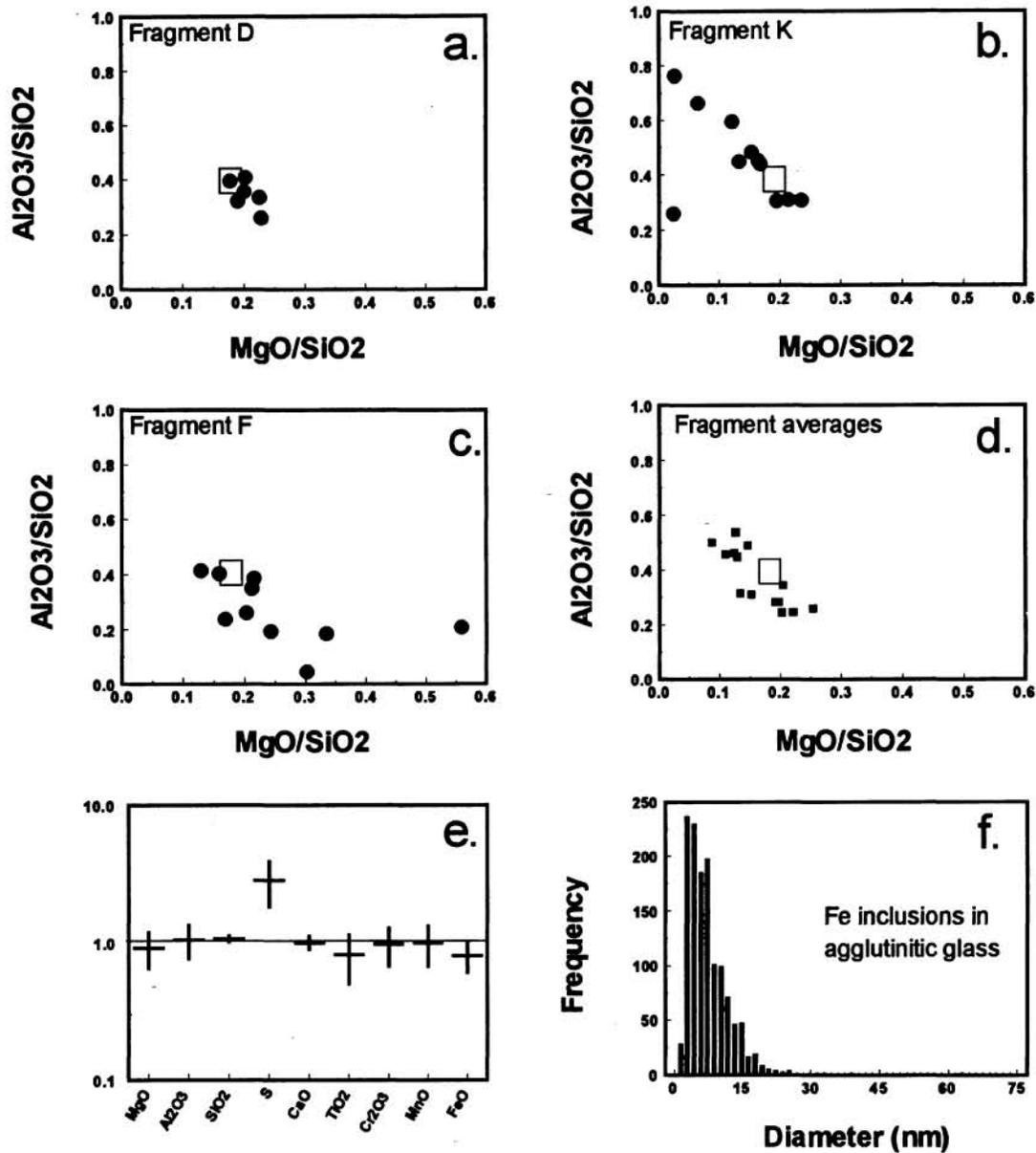


Figure 1a-1c. Plots of MgO/SiO_2 (wt.%) versus $\text{Al}_2\text{O}_3/\text{SiO}_2$ (wt.%) for individual fragments of agglutinitic glass showing a.) Group I, b.) Group II, and c.) Group III patterns (open square is the ratio for the $>10 \mu\text{m}$ size fraction (from [4]), see text for details). Figure 1d shows the composition of each individual fragment obtained by combining the analyses from different regions within the same fragment to obtain an average. Figure 1e. The average composition of analyzed agglutinitic glass fragments relative to the bulk composition of the $>10 \mu\text{m}$ size fraction (from [4]) of 10084. Figure 1f. A plot of the average size distribution of Fe grains in the analyzed agglutinitic glass fragments.