ANALYTICAL ELECTRON MICROSCOPY OF FINE-GRAINED GLASS SPHERES IN APOLLO 16 SOIL 61181. Lindsay P. Keller and David S. McKay, SN14, NASA-Johnson Space Center, Houston TX 77058

Introduction. The compositions of lunar glasses have been used to infer the compositions of major rock types, to characterize differing soils and regolith breccias, and to understand the processes involved in glass formation [*e.g.*, 1-4]. We report here the results of a transmission electron microscope (TEM) study of the fine-grained glass spheres in Apollo 16 soil sample 61181. We found evidence for extreme volatilization from impacts that formed abundant micron-sized high-Al, Si-poor (HASP) [5] glasses. Some of these glasses are the most aluminous yet reported from lunar samples.

Experimental. Sample 61181 is a mature soil characterized by abundant agglutinates and a high I_s/FeO ratio (82) [6]. We prepared TEM specimens of 61181 by embedding aliquots of the <20 μm fraction in low viscosity epoxy and sectioning using diamond knife ultramicrotomy. The microtomed sections (<100 nm thick) were analyzed quantitatively using energy dispersive X-ray spectroscopy (EDS) in the TEM.

Results. We analyzed nearly 50 micrometer-sized, vesicle-free glass spheres in 61181. The spheres are circular in cross-section and show only diffuse scattering in their electron diffraction patterns. It is difficult to determine the original diameters of glass spheres in microtomed sections (the cross-sections of the glass spheres are < 1 μm in diameter). We note that particles larger than ~ 5 μm in diameter in the sections tend to fracture during slicing, and so we estimate that the original diameters were probably <5 μm.

The majority of EDS analyses fall into 3 main compositional groups (group names from refs. 1 and 5), highland basalt glasses, plagioclase glasses, and high-Al, Si-poor (HASP) glasses. Minor glass types present in 61181 include: low-Ti and high-Ti mare basalt glasses, low-K Fra Mauro basalt glass, high silica glass (SiO_2>90 wt. %), and K- and Fe-rich silica glass.

Of particular interest is the abundance and composition of HASP glasses in 61181. HASP glasses comprise nearly 50% (22 of 48) of the glasses analyzed in this study. The HASP glasses are Al- and Ca-rich, and Si- and Fe-poor. In 61181, HASP glasses show a wide compositional range, from plagioclase (An95) to an extraordinarily Al- and Ca-rich, Si-poor glass (Al_2O_3=65%, CaO=28%, SiO_2=6%, MgO, FeO, and TiO_2 < 1%, all in wt. %) (Figure 1). This is the most aluminous glass yet reported from studies of lunar materials. The high-Al HASP glasses are also very Si-poor; of the 9 spheres that contain >47 wt.% Al_2O_3, 5 contain <25 wt. % SiO_2. The ratio of CaO/Al_2O_3 (in wt.%) for the HASP glasses is relatively constant [0.5 ($\pm$0.1)] and is independent of SiO_2 content.

Two unusual types of silica-rich glass occur in 61181. The first is a volatile-rich (Na, K, S, P), Al-poor (VRAP) silica glass with numerous small (<10 nm) Fe inclusions, while the second is >90 wt. % SiO_2. The VRAP glasses contain > 5 wt. % K_2O and thus resemble the "granitic" glasses and the mesostases described by others [1-3]. One important difference however, is that the granitic glasses contain appreciable Al (~10 to 15 wt.% Al_2O_3), whereas the VRAP glasses contain very little Al (< 5 wt.% Al_2O_3).

Discussion. HASP glasses have been described previously from Apollo 14 regolith fines [7], Apollo 14 regolith breccias [8] and from Apollo 16 drill cores [5]. HASP glasses are believed to be derived from aluminous source rocks via impact melting and concomitant vaporization of silica, leaving a refractory residue [5-7]. Finkelman [7] noted that HASP glasses were restricted to fine grain sizes, and inferred that a high surface area was necessary to allow for sufficent volatilization to occur. Vaniman [8] suggested that the HASP glass compositions could be used to infer crustal or regolith compositions, and that multiple HASP trends were present in Apollo 14 regolith breccias.

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Multiple HASP glass trends are also present in 61181 (Figure 2). The majority of HASP glasses are Al-rich (Al_2O_3 >35 wt. %) and are probably derived from an anorthite-rich source material (either highland anorthositic breccias or the bulk soil). These glasses are compositionally similar to the high-Al HASP glasses reported from an exotic Apollo 14 breccia [8]. However, in the Apollo 14 sample, the high-Al HASP glasses are crystalline (yoshiokaite) and occur as angular clasts [8].

A smaller group (4) of HASP glasses in 61181 are derived from mare basalts, and thus resemble the Apollo 14 HASP trend described by [8]. The HASP glasses derived from mare basalts contain more Ti (up to 10 wt. % TiO_2) and Fe (5 to 15 wt. % FeO) than the HASP glasses derived from highland rocks/plagioclase. The mare HASP trend is shown in a plot of Al_2O_3 vs. SiO_2 (Figure 2).

The VRAP glasses in 61181 are compositionally distinct from the granitic glasses described by others [1-3]. We suggest that the VRAP glasses may be condensation products from an impact-generated vapor. We propose that in a large impact, sufficent material could be vaporized such that some of the material condensed as glass spheres. However, the paucity of VRAP glass spheres in 61181 indicates that most of the vaporized material condensed on nearby grains as suggested by others [*e.g.*, 9, 10].

Conclusions. HASP glasses are abundant in the fine-grained fraction of soil 61181. Their abundance indicates that surface area effects are important in their genesis. Clearly, extreme vaporization must have occurred in order to generate the very high-Al HASP in 61181. The majority of the HASP glasses are probably derived from the bulk soil, although a few are derived from mare basalts. The HASP glasses formed in response to extreme volatilization during impacts. Part of the vaporized material recondensed as droplets of volatile-enriched silica glass.

References. [1] Reid, A. M. *et al.* (1972) *Proc. 3rd LPSC*, 363. [2] Simon, S. B. and Papike, J. J. (1982) *Proc. 13th LPSC*, A232. [3] Walker, R. J. and Papike, J. J. (1981) *Proc. 12th LPSC*, 421. [4] Wentworth, S. J. and McKay, D. S. (1988) *Proc. 18th LPSC*, 67. [5] Naney, M. T. et al. (1976) *Proc. 7th LPSC*, 155. [6] Morris, R. V. et al. (1983) *Handbook of Lunar Soils, Part II.*, JSC #19069. [7] Finkelman, R. B. (1973) *Proc. 4th LPSC*, 179. [8] Vaniman, D. T. (1990) *Proc. 20th LPSC*, 209. [9] Kerridge, J. F. and Kaplan, I. R. (1978) *Proc. 9th LPSC*, 1687. [10] Devine, J. M. *et al.* (1982) *Proc. 13th LPSC*, A260.

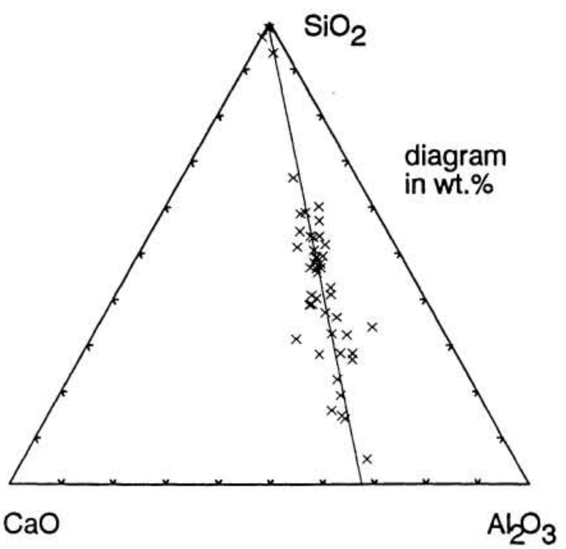

Figure 1. Compositions of glass spheres in 61181 projected onto a CaO-Al_2O_3-SiO_2 ternary. The line connects the SiO_2 corner with the estimated end member "highland" HASP composition (~$CaAl_2O_4$).

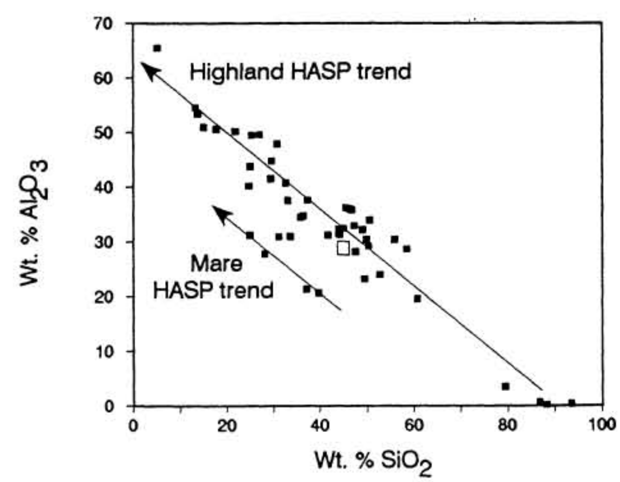

Figure 2. A plot of Al_2O_3 *vs.* SiO_2 for glass spheres in 61181. Highland- and mare-HASP trends are shown as solid lines. The bulk soil composition is indicated by the open square.

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