

Serenitatis Basin impact event either by impact erosion or by assimilation during intense magmatic activity, or (3) impact dynamics during basin formation prevented upper crustal rocks from being included in the excavated impact melt.

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**IMPACT GLASSES FROM THE <20- $\mu$ m FRACTION OF APOLLO 17 SOILS 72501 AND 78221.** John A. Norris<sup>1</sup>, Lindsay P. Keller<sup>2</sup>, and David S. McKay<sup>2</sup>, <sup>1</sup>Department of Geology, University of Georgia, Athens GA 30602, USA, <sup>2</sup>Code SN, NASA Johnson Space Center, Houston TX 77058, USA.

**Introduction:** The chemical compositions of microscopic glasses produced during meteoroid impacts on the lunar surface provide information regarding the various fractionation processes that accompany these events. To learn more about these fractionation processes, we studied the compositions of submicrometer glass spheres from two Apollo 17 sampling sites using electron microscopy. The majority of the analyzed glasses show evidence for varying degrees of impact-induced chemical fractionation. Among these are HASP glasses (high-Al, Si-poor), which are believed to represent the refractory residuum left after the loss of volatile elements (e.g., Si, Fe, Na) from the precursor material [1–3]. In addition to HASP-type glasses, we also observed a group of VRAP glasses (volatile-rich, Al-poor) that represent condensates of vaporized volatile constituents, and are complementary to the HASP compositions [3]. High-Ti glasses were also found during the course of this study, and are documented here for the first time.

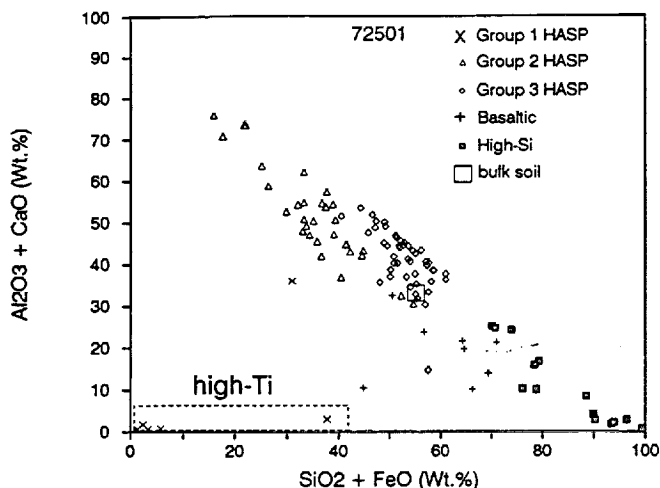


Fig. 1. Compositions of submicrometer glasses in soil 72501.

TABLE 1. Average EDX analyses for subgroups of impact glasses in soils 72501 and 78221.

	1a	1b	2	3	4	5*
MgO	7.0	4.0	9.0	6.0	14.0	3.1
Al <sub>2</sub> O <sub>3</sub>	53.0	4.0	34.0	27.0	14.0	5.2
SiO <sub>2</sub>	10.0	7.5	30.0	49.0	46.0	65.0
CaO	23.0	1.5	18.0	11.0	9.0	2.1
TiO <sub>2</sub>	3.3	64.0	3.0	1.0	3.0	0.6
FeO	3.7	19.0	6.0	6.0	14.0	20.0

\* High-Si glasses contain <2 wt.% each of Na<sub>2</sub>O, K<sub>2</sub>O, SO<sub>3</sub>, P<sub>2</sub>O<sub>5</sub>, MnO, and Cr<sub>2</sub>O<sub>3</sub>.

1a = group 1 HASP; 1b = group 1, high-Ti; 2 = group 2 HASP; 3 = group 3 HASP; 4 = basaltic glasses, and 5 = high-Si glasses.

**Experimental:** Samples from the <20- $\mu$ m size fractions of two Apollo 17 soil samples (72501 from station 2 at the base of the South Massif, and 78221 from station 8 at the base of the Sculptured Hills) were embedded in low viscosity epoxy and cut into thin sections (~80–100 nm thick) using diamond-knife ultramicrotomy. The thin sections were analyzed using a PGT energy-dispersive X-ray (EDX) spectrometer with a JEOL 100CX TEM. EDX analyses were obtained for 107 spheres from 72501 and 115 from 78221. The apparent diameters of these spheres in thin section were typically between 100 and 400 nm, although the true diameter of any actual sphere may have been slightly larger. The relative errors associated with the EDX analyses were estimated by analyzing a grossular standard. The relative errors for Al, Si, Ca, and Fe are ~5%. These relative errors increase significantly for concentrations <5 wt%.

The glass compositions were initially divided into a "high-Si" group (SiO<sub>2</sub> > 60 wt%) or a "low-Si" group (SiO<sub>2</sub> < 60 wt%). For the "low-Si" compositions a standard CIPW norm was calculated. However, many of these glasses (e.g., HASP) contain insufficient Si to be used with this method. For these Si-poor compositions, a new normalization scheme was developed using three groups of progressively Si-deficient normative minerals. Group 1 HASP compositions contain insufficient Si to calculate any normative anorthite (AN). Instead, the group 1 normative mineralogy includes gehlenite (GH) + spinel (SP) + Ca aluminates. Group 2 HASP compositions consist of normative GH + AN + SP + olivine + Ca aluminates. The group 3

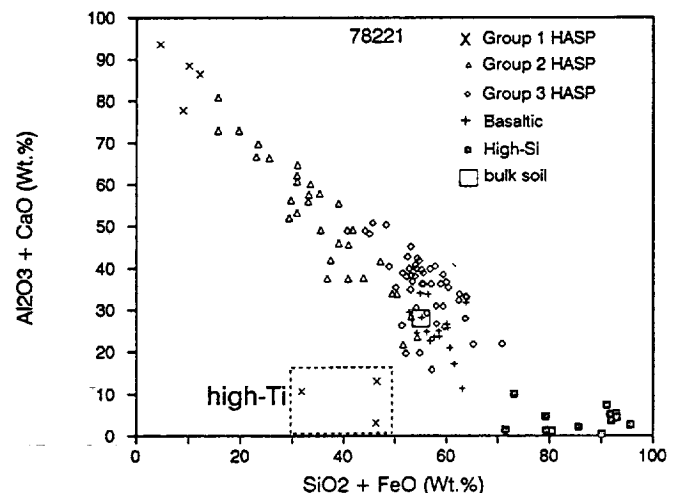


Fig. 2. Compositions of submicrometer glasses in soil 78221.

HASP compositions are cordierite- or mullite-normative, and contain excess  $\text{Al}_2\text{O}_3$  and  $\text{SiO}_2$  after using all of the Ca, Na, and K to make normative feldspar.

**Results and Discussion:** The compositions of the 107 glasses analyzed from sample 72501 and the 115 from 78221 are plotted in Figs. 1 and 2. The compositions range from nearly 95% refractory components to others composed entirely of more volatile components. HASP compositions comprise ~75% of the total glasses analyzed in each sample. The group 1 HASP glasses comprise ~6% of the total analyses from both 72501 and 78221. The group 1 HASP compositions are the most refractory and the most volatile-depleted of all the analyzed glasses. A cluster of high-Ti glasses were included within group 1 and plot about the origin in Fig. 1. The group 1 high-Ti glasses contain little Ca or Al, but nonetheless have undergone extreme volatile loss in the form of nearly complete removal of Fe from what was once ilmenite (Table 1). The other group 1 members are probably derived from mostly anorthositic material that has lost most of its original  $\text{SiO}_2$  content. All but one of the 72501 group 1 HASPs are high-Ti glasses, whereas 78221 contains a larger proportion of the Ca- and Al-rich members of this group (Table 1).

The group 2 HASP glasses span a much wider compositional range in both samples, and comprise 29% of the analyses from 72501 and 27% of those from 78221. These have undergone a lesser degree of volatile loss than those of group 1, and generally retain significant amounts of  $\text{SiO}_2$  and FeO, even though considerable amounts of these components have been lost. The average composition of group 2 glasses (in wt%) from both samples is given in Table 1. The similarity in both the relative proportions and the average compositions of the group 2 HASP glasses in these two samples reflects the similarities in bulk soil composition and soil maturity at these two sites. We note that glasses fractionated to the extent of the group 1 and 2 HASP compositions seem to occur only among the finest size fractions.

The group 3 HASP glasses have the least fractionated compositions. The glasses of this compositional type in both samples comprise a larger proportion of the analyzed population than does any other single group (44% of 72501 and nearly 42% of 78221), and the average composition of this group is very similar in both samples (Table 1).

The high-Si glasses are comprised of the relatively volatile elements and are compositionally complementary to the HASP glasses. These compositions make up 13% of the 72501 analyses and 11% of the 78221 population. The compositions of these glasses in both samples span the range from nearly pure  $\text{SiO}_2$ , sometimes with other associated volatiles such as Na, K, P, and S, to other Si-rich compositions with high Fe concentrations (Table 1). It is believed that the compositions of this group represent the recondensation of impact-generated vapors [3]. As with most of the HASP glasses, these Si-rich compositions are only found among the finest size fractions of lunar soils. This suggests that such extreme fractionations only occur at sizes where the surface-area-to-volume ratio is high enough to allow the degree of melting and vaporization required to produce these unusual compositions.

In both samples, the glasses of basaltic composition constitute a relatively small group, being just over 8% of the analyses from 72501 and nearly 14% of those from 78221. These compositions display little or no observable volatile loss. The average composition of this group (in wt%) from both samples is given in Table 1.

**Conclusions:** We found that the majority of the analyzed glasses in both soils either have refractory compositions resulting from volatile loss, or are volatile-rich condensates of impact-generated vapors. In both samples, the three HASP groups comprise ~75% or more of the total number of analyzed glasses. The HASP glasses are

derived from the bulk soil and from the feldspathic component of the soils through the loss of major amounts of Si and lesser quantities of Fe and alkalis. The Si-rich glasses rival the number of the unfractionated basaltic glasses. The pronounced fractionations (volatilization and condensation) that occur in the submicrometer size range result from the large surface-area-to-volume ratio of the glasses.

This is the first report of high-Ti glasses from lunar soils. Considering all high-Ti glasses from both samples together, a trend is observed that begins with Fe-Ti-rich compositions and extends to glasses that consist of nearly pure  $\text{TiO}_2$ . We conclude that these compositions originate by the loss of Fe from ilmenite, which is the dominant Ti-rich oxide at the Apollo 17 site. These high-Ti glasses are one of the few types of impact glasses derived from a specific mineral constituent of lunar soils.

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ISOTOPIC AGES AND CHARACTERISTICS OF ANCIENT (PRE-SERENITATIS) CRUSTAL ROCKS AT APOLLO 17. W. R. Premo and M. Tatsumoto, U.S. Geological Survey, MS 963, Box 25046, Federal Center, Denver CO 80225, USA.

**Problems with the Isotopic Systematics in Lunar Samples:**

Four different decay schemes, K-Ar, Rb-Sr, Sm-Nd, and U-Pb, have predominantly been used for age determinations on lunar rocks. These radiometric systems are particularly useful because they have long half-lives that are on the same scale as most lunar rock ages, which is necessary in order to obtain the most precise ages [1]. However, none of these systems is without problems when applied to lunar samples. In order for any single radiometric system to yield a primary crystallization age, it must remain closed from the time of crystallization until the present, without addition or loss of either parent or daughter isotopes. After many years of isotopic work, investigators have come to realize that most lunar samples (nearly all ancient highland samples) have been metamorphosed and their isotopic systematics disturbed [2]. Many studies report completely reset and partially reset Ar-Ar ages— $^{40}\text{Ar}$  loss readily occurs during impact metamorphism. However, some Ar-Ar ages agree quite well with other radiometric ages from the same sample, illustrating that Ar is not lost in some lunar samples. Reports of disturbances in the Rb-Sr and U-Pb systems [2-4] as well as the Sm-Nd system [3] are also prevalent in the lunar literature. Disturbed Rb-Sr isochron ages are normally explained by either mobility of both elements or mixing due to brecciation. The Sm-Nd system appears to be the most retentive, although some problems have also been noted. U-Pb and Th-Pb isochron ages typically date metamorphic events [5]. Fortunately, there are two U-Pb systems that can be compared simultaneously in a concordia diagram to "look through" disturbances. This attribute of the U-Pb systems is most desirable when working with lunar samples, and helps to identify both the age of the rock and the age of the disturbance. A major drawback of this approach is the necessity for initial Pb corrections in order to calculate radiogenic Pb/U ratios [5,6]. Initial Pb compositions are typically defined by the y-intercepts on U-Pb and Th-Pb isochron diagrams, but because most U-Pb and Th-Pb isochrons for lunar samples are disturbed, the initial Pb values are undefined and therefore must be assumed. This situation has been confronted with norite 78235 [5]. A possible solution to the problem is to use an age (hopefully accurate), perhaps determined using one of the other dating techniques, and back calculate what the initial Pb values must be in order to produce the same age with the two U-Pb