APOLLO 16 MAFIC GLASS: GEOCHEMISTRY, PROVENANCE, AND IMPLICATIONS. R. A. Zeigler, R. L. Korotev, B. L. Jolliff, L. A. Haskin, and C. Floss, Dept. of Earth and Planetary Science and the McDonnell Center for Space Sciences, Washington University, 1 Brookings Dr., Campus Box 1169, St. Louis, MO, 63130; *zeigler@levee.wustl.edu.

Overview: Although the Apollo 16 mission landed in the feldspathic lunar highlands, mass-balance models suggest that there is a 5-6% mare component in the mature soils collected at the site [1,2]. Only one mare basalt >1 cm was found [3] and two surveys of 2-4 mm particles [4,5] found that <1% of this size fraction is mare basalt. Similar surveys of the <1 mm size fraction of A16 soils found very little lithic mare basalt, but several percent of basaltic green, yellow, and orange glass [6,7]. The green glass beads were identified as VLT picritic glass [8-9] and the orange/yellow glass shards were a mix of high and low Ti mare-like glass, high-Al basaltic glass, and KREEPy glasses [2,10].

Most previous studies of glasses in the A16 regolith were surveys that identified a high proportion of feldspathic glass [e.g., 11] because most of the glass is produced by local impacts. Because the number of mafic glasses found was low, few compositional groupings were identified. As part of our ongoing study of the mafic components of the Apollo 16 site [4,12], we specifically targeted mafic glasses from Apollo 16, selecting against the more feldspathic glasses. In this way we were able to identify over 300 mafic glasses (>10 wt % FeO). We present here the major- and trace-element chemistry of the main glass groups and discuss the likely provenance of each group.

Methods: We analyzed a total of 18 thin sections from drill core 68001 and grain mounts from soils 68501, 65701, 65511, 62281, and 60601. Grain size ranged from 75 to 525 μm, with most grains in the 75-150 μm range. Major element compositions were determined by electron microprobe analysis (Table 1). Trace element compositions were determined by ion microprobe analysis.

Results/Discussion: On the basis of their major element compositions we have identified 6 compositional groups among the 300 mafic glasses analyzed (comprising ~60% of the glasses): very low-Ti green glass beads (GGBs), low-Ti basaltic glass, high-Ti basaltic glass, high-Al basaltic glass, basaltic-andesite glass, and KREEPy glass. Preliminary trace-element data indicate that these groups are robust for trace- as well as major-element compositions.

GGBs. This group has a major- and trace- element composition consistent with the pyroclastic VLT green glass previously described at the Apollo 16 site [8,9]. The provenance of the A16 GGBs is unknown; in fact, no known VLT pyroclastic deposits have been identified on the Moon (despite the presence of VLT picritic glass at 5 of the 6 Apollo sites).

Low-Ti basaltic glasses. This glass group has a major element composition almost identical in composition to A12 pigeonite basalts (e.g., 20 wt % FeO, 4 wt % TiO_2). No glasses with this composition have previously been reported in surveys of A16 glass, although such glass may have been included in averages that included lower FeO and TiO_2 glasses. The only transport mechanism for getting mare material to the A16 site is by post-basin lateral transport due to small to moderate impacts into the surrounding maria [12]. Mare Nectaris is by far the closest (~220 km) and most extensive low-Ti mare (~4% TiO_2; [12]) to the Apollo 16 site. Within Nectaris, the Copernican-age craters Theophilus (100 km), Madler (30 km), and Torricelli (30 km) are likely source craters for low-Ti mare glass at the A16 site.

High-Ti basaltic glasses. This group has a major-element composition (e.g., 18 wt % FeO, 9 wt % TiO_2) similar to high-Ti mare basalts. The trace-element chemistry is also consistent with other high-Ti mare basalt compositions (77 ppm Sc, low LREE/HREE ratio). Glasses of similar composition have been described in other surveys of A16 glass [10–12]. Mare Tranquillitatis is the closest (~300 km) and largest high-Ti mare to the Apollo 16 site. Furthermore, several small Eratosthenian and Copernican craters occur along the southern edge of Mare Tranquillitatis that are possible source craters for the high-Ti basaltic glasses. Dionysus in par-

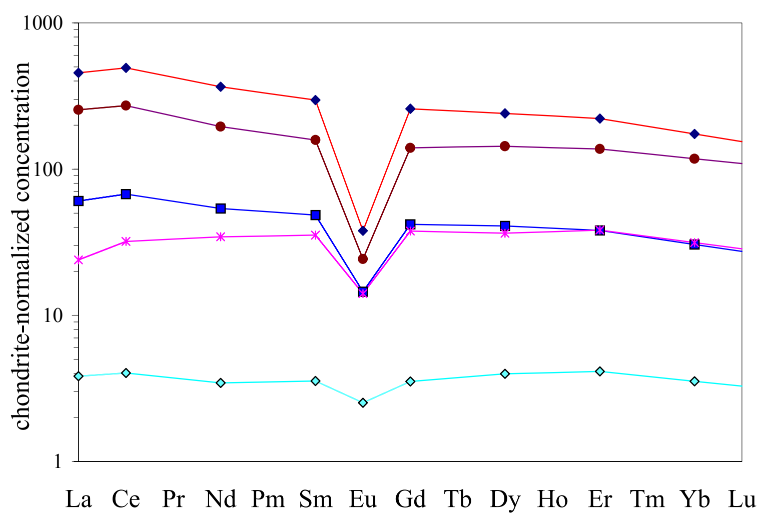

Figure 1: REE concentrations for the glass groups discussed in this abstract. Both the Si-rich basaltic (bas.) glasses (gls.) and KREEPy glasses have a KREEP-like pattern. The shapes of the patterns for high-Ti and high-Al basaltic glasses are similar to mare basalts with similar major element compositions, as is the A16 green glass bead pattern.

ticular has rays that are elevated in both TiO_2 and FeO that extend into the highlands, directly toward the Apollo 16 site [13].

High-Al basaltic glasses. This group has a major-element composition that is broadly similar to, though somewhat less mafic than, other high-Al mare basalts (e.g., 14.6 wt % FeO, 3.9 wt % TiO_2; 14.6 wt % Al_2O_3). The major-element composition could also be explained as a mixture of mare basalt with ~6 wt % TiO_2 and typical material of the feldspathic highlands. The REE pattern of this group (Fig. 1) is not consistent with this mixing scenario, however. Although difficult to verify with remote sensing, the most straightforward explanation of the provenance of this group is Mare Nectaris (based primarily on its TiO_2 concentration), again delivered by Theophilus.

Basaltic-andesite composition glasses. The compositions of the glasses in this group does not closely match that of any glass or rock previously observed in the lunar sample collection, although glasses of this composition were previously observed by [14,15]. This group has moderate concentrations of FeO and TiO_2 (13.3 and 3.6 wt % respectively), high concentrations of alkalis and phosphorus (1 wt % Na_2O, 0.7 wt % K_2O, 0.5 wt % P_2O_5), is ferroan (Mg' = 39), and silica-rich with 52.5 wt % SiO_2. The ITE concentrations are higher than that of the KREEP component of Apollo mafic melt breccias [16], although the REE pattern has a similar shape (Fig. 1). The composition of this group of glasses, particularly the high SiO_2 and low Mg' compared to KREEP impact-melt breccias, cannot be explained as a mixture of known lunar rock types. The high concentrations of ITEs suggests that this group of glasses is a product of the PKT (Procellarum KREEP Terrane). Glasses of this composition are almost entirely absent from the A16 ancient regolith breccias (ARBs), however [14,15]. This occurrence means that it is unlikely that that they were deposited at the A16 site either prior to, or by, the Imbrium impact (which likely formed the ARBs [12,17]). Perhaps one of the later impacts such as Copernicus, Eratosthenes, Archimedes, Aristillus deposited them at the site. These craters are all relatively small and distant, which makes it unlikely that they deposited a significant amount of material at the Apollo 16 site. Nonetheless, the PKT seems to be the only likely source region for these glasses.

KREEPy glass. This group of glasses is the same as that which has previously been designated high-K Fra Mauro (HKFM) "basaltic" glass [2,10,14,15]. Our ion-probe results show it to have a KREEP-like REE pattern (Fig. 1) and the bulk composition is generically that of KREEP, but is richer in SiO_2 and TiO_2 and has a lower Mg' (54) than most rocks identified as KREEP. These glasses derive from an evolved lunar lithology, and hence most likely originate from within the PKT.

Conclusions: To first order, this study confirms that the mafic glasses in the Apollo 16 regolith are an approximately equal mix of mare basalt-like glasses from the surrounding maria and KREEPy glasses likely derived from the PKT. Furthermore, this study and the recent study by Zellner et al. [11] shows that a significant fraction of the fine-grained glass in the A16 regolith (1) is considerably more mafic than the A16 soil and (2) clearly was not formed from the local soil by the impacts of micrometeorites, i.e., it is not glass from agglutinates formed from the Apollo 16 regolith. The high relative abundance of fine-grained, mafic glass of distant origin in the Apollo 16 regolith accounts, at least in part, for the anomalous mafic nature of "agglutinitic glass" and finer grain-size fractions of Taylor et al. [18]. The presence of numerous small fragments of mafic glass at the Apollo 16 site yet its absence as "rocks" attests to a mechanism for efficiently dispersing fine-grained material.

References: [1] Korotev (1997) *MAPS, 32,* 447-78. [2] Kempa and Papike (1980) *PLPSC, 11,* 1635-61. [3] Delano (1975) *PLPSC 6,* 15-47. [4] Delano et al. (1974) *PLPSC, 4,* 537-51. [5] Zeigler et al. (2000) *LPS XXXI,* #1859. [6] Houck (1982) *PLSPC., 13,* A210-20. [7] Houck (1982) *PLSPC., 13,* A197-209. [8] Shearer and Papike (1993) *GCA, 57* 4785-812. [9] Delano (1986) *PLPSC, 16,* D201-213. [10] Naney et al. (1997) *Icarus., 32,* A74. [11] Zellner et al. (2003) *LPS XXXIV*, #1157. [12] Zeigler et al. (1996) *LPS XXXIV,* Abstract #1454. [13] Morris and Wilhelms (1967) *USGS map of Julius Caesar Quadrangle.,* I-510. [14] Wentworth and McKay (1988) *PLPSC 18,* 67-77. [15] Simon et al. (1988) *EPSL, 89* 147-62. [16] Korotev (2000) *JGR, 105* 4317-45. [17] Korotev (1997) *MAPS, 32,* 447-78. [18] Taylor L. A., et al. (2003) *LPS XXXIV*, #1774. **Acknowledgements:** This work was supported by NASA grant NAG5-XXXX through L. Haskin.

Table 1

Sample (N)	GGB (13)	s.d.	LT (41)	s.d.	HT (17)	s.d.	BA (24)	s.d.	HA (27)	s.d.	KR (53)	s.d.
SiO2	44.1	0.36	45.8	0.67	41.5	0.49	52.5	0.94	44.2	0.52	50.8	1.19
TiO2	0.43	0.094	4.06	0.280	8.58	0.534	3.58	0.191	3.89	0.242	2.47	0.399
Al2O3	7.9	0.11	10.1	0.54	10.5	0.55	12.9	0.35	14.6	0.44	15.5	0.84
Cr2O3	0.47	0.037	0.30	0.089	0.44	0.068	0.13	0.035	0.35	0.031	0.18	0.053
FeO	21.7	0.23	20.2	0.39	17.9	0.51	13.3	0.31	14.6	0.39	11.2	0.60
MnO	0.26	0.033	0.26	0.055	0.25	0.042	0.18	0.037	0.19	0.032	0.15	0.031
MgO	16.7	0.23	8.7	0.98	9.0	0.69	4.8	0.36	10.3	0.31	7.9	1.27
CaO	8.4	0.09	9.6	0.43	10.9	0.35	9.1	0.27	11.0	0.16	9.9	0.53
Na2O	0.17	0.022	0.28	0.136	0.34	0.140	0.97	0.157	0.49	0.113	0.73	0.323
K2O	b.d.	0.003	0.13	0.070	0.05	0.039	0.68	0.117	0.09	0.027	0.52	0.247
P2O5	0.04	0.011	0.07	0.050	0.09	0.037	0.51	0.248	0.11	0.041	0.18	0.221
Sums	100.3		99.4		99.5		98.6		99.8		99.5	
Mg'	58		43		47		39		56		55	

LT=low-Ti basaltic glass, HT=high-Ti basaltic glass, BA=basaltic andesite glass HA=high-Al basaltic glass, s.d. = standard deviation, (N)=the number of glasses averaged, Mg'=Mg/(Mg+Fe)*100