GEOCHEMISTRY AND IMPACT HISTORY AT THE APOLLO 16 LANDING SITE. N.E.B. Zellner[1,4], P.D. Spudis[2], J.W. Delano[3], D.C.B. Whittet[4], and T.D. Swindle[5] [1]Institute of Geophysics and Planetary Physics, Lawrence Livermore National Laboratory, Livermore, CA 94550 zellner1@llnl.gov, [2]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723, [3]New York Center for Studies on the Origin of Life, Department of Earth and Atmospheric Sciences, University at Albany (SUNY), Albany, NY 12222, [4]New York Center for Studies on the Origin of Life, Rensselaer Polytechnic Institute, Troy, NY 12180, [5]University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721.

Introduction: Lunar impact glasses possess the unmodified refractory element ratios of the original fused target materials at the sites of impacts. These target materials are usually regolith. 866 glasses from the Apollo 16 landing site have been analyzed by electron microprobe in this study. These glasses show significant variation and hint at the existence of highland basalt (HB) regolith compositions atypical of the usual HB compositions historically found at the Apollo 16 site [1]. Additionally, a large number of mare glasses have been identified. Clementine color image data have been used to construct iron, titanium, and aluminum maps for comparison with the sample database. These maps suggest that the Apollo 16 landing site is largely composed of anorthositic material and that mare compositions are not found close by. Nine of these impact glasses have been dated by the $^{40}Ar/^{39}Ar$ technique and may be used to constrain the impact history at the Apollo 16 landing site. These results illustrate how lunar impact glasses together with orbital data can provide geochemical constraints on the local and regional geology of the Moon [2,3,6].

Lunar Impact Glasses: Lunar impact glasses are droplets of melt produced by energetic cratering events that were quenched during ballistic flight. They possess the refractory element ratios of the original fused target materials at the site of impact [4]. Impact glasses offer the potential for providing information about local and regional units and terrains. Although glass compositions have been interpreted as having rock compositions, based on rock types at the collection sites [1,5], this study uses orbital data to show that glass composition(s) most often represent regolith composition(s).

Sample Analysis: This study reports the largest data set of Apollo 16 glasses ever published. All 866 glasses from Apollo 16 were analyzed for Si, Ti, Al, Cr, Fe, Mn, Mg, Ca, Na, and K using a JEOL 733 electron microprobe in the Department of Earth and Environmental Sciences at Rensselaer. These glasses, which include both impact-produced and volcanic varieties, are from the following regolith samples: 64501,225; 66041,127; 60014,6017; 60014,6032; 60014,6035; 60014,6038; 60014,6041; 60014,6044; 64001,6023; 64001,6032; 64001,6033; 64001,6040; 64001,6041; 64001,6042; and 64001,6043.

Five X-ray spectrometers were tuned and calibrated for each element analyzed in the glass sample. A 15 keV electron beam with a specimen current of 50 nAmps was used. Lunar working standards were used to assess analytical precision throughout the study. Count-times of 200 seconds were used for Na and K, while count-times of 40 seconds were used for the other elements. Backgrounds were collected for every element on every analysis. Uncertainties in the measurements were usually < 3% of the amount present.

Nine impact glasses from 64501 were subsequently irradiated and analyzed in order to determine their $^{40}Ar/^{39}Ar$ ages. Samples were irradiated in the Phoenix Ford Reactor at the University of Michigan for about 300 hours, producing a J-factor of 0.05776 ± 0.00030. CaF_2 salts and MMhb-1 hornblende samples were irradiated simultaneously, the former to correct for reactor-produced interferences and the latter to determine the neutron fluence. Laser step-heating on these 9 samples was carried out in the University of Arizona noble gas lab, using a continuous Ar-ion laser heating system. Heating steps were determined by passing a 5A beam over the sample. The amperage was then increased incrementally until ^{40}Ar counts from the sample peaked then decreased to no greater than background levels. In addition to system blank and interference corrections, Ar isotopes produced by cosmic ray spallation and by implantation from the solar wind were subtracted from each sample.

Results: Chemical analyses of impact glasses from regoliths 64501, 66041, 60014, and 64001 are shown in Figure 1. This plot shows that impact glasses from the Apollo 16 site comprise at least two broad compositional groups. The most populous group plots to the lower right of the ternary diagram and is composed mostly of HB compositions [1]. A small subset of this group has a composition similar to that of the lunar meteorites and to that of the highland basalt glasses found in the Apollo 14 regolith [2,6], indicating that not all HB compositions are the same. The second-most populous group is a diffuse cluster of glasses that plots in the left-of-center portion of the ternary diagram, and is similar to, but not the same as, the KREEPy regolith at the Apollo 14 site [2,3,6].

Orbital geochemical data [2,3,7] indicate that the Apollo 16 region is KREEP-poor, which is concordant with the observation that most of our impact glasses are KREEP-poor. However, KREEP-rich and mare-derived glasses within our suite of glasses indicate that some of those exotic glasses have apparently been transported at least 250 km from the nearest exposure of mare materials in Mare Nectaris [8].

$^{40}Ar/^{39}Ar$ ages for the 9 impact glasses from 64501 are seen in Table 1. When plotted with chemical composition (Figure 2), it is clear that 2 impact events are quite apparent, one at ~800 Ma and another at ~3800 Ma. The range of compositions in these glasses reflects a trend from mare (upper y-axis) to highland (lower y-axis) compositions, indicating that they may have been produced by impact events occurring in a region possessing a mare-highland border.

Conclusions: Analyses of 866 impact glasses show that the geochemistry and impact history at the Apollo 16 site is complicated. Regolith samples from the Apollo 16 site show that at least 2 kinds of HB material are present, one historically attributed to typical Apollo 16 "dirt" [1] and one typical of the compositions of lunar meteorites and pre-Imbrium material [2,6]. Thus, not all HB compositions are the same. Additionally, the presence of glasses possessing mare compositions (ranging from high-Ti to low-Ti) indicates that ballistic transport of material from great distances on the Moon is not an unusual phenomenon.

$^{40}Ar/^{39}Ar$ ages from 9 impact glasses show that the Moon experienced significant impacts at ~800 Ma and at ~3800 Ma, somewhere in the vicinity of the Apollo 16 landing site. We suggest that these glasses represent at least two distinct impact events at separate times on similar terrains, which must have included both mare and highlands compositions. Candidate craters include Theophilus and Cyrillus, both of which border the maria, ~250 km east of the Apollo 16 landing site. Our studied glasses could represent 9 distinct impacts; however, the similar compositions of the glasses (Figure 2), suggest that they originated in the same region and reflect the composition of the pre-impact site stratigraphy, as in the case of some tektites [e.g. 9].

We have shown here that a combination of chemical composition and ages for impact glasses allows for a more substantive interpretation of the lunar impact history. Histograms alone are not sufficient.

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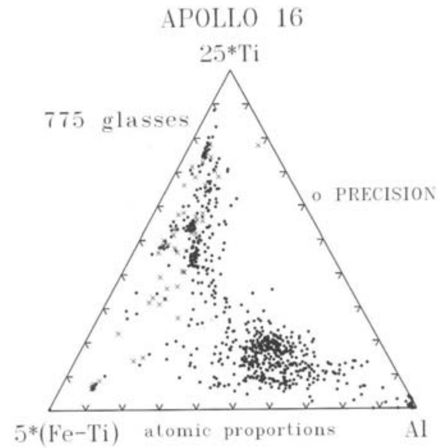

Figure 1. Impact glasses from regoliths 64501, 66041, 60014, and 60041.

Sample #	Age (Ma)	1σ Uncertainty (Ma)
223	3785	5.0
187	3673	7.0
225	3739	10.4
185	3781	8.8
277	3915	9.6
195	686	4.0
254	849	6.0
251	805	87.0
239	777	6.0

Table 1. Ages of 9 glasses from regolith sample 64501 with 1σ uncertainties.

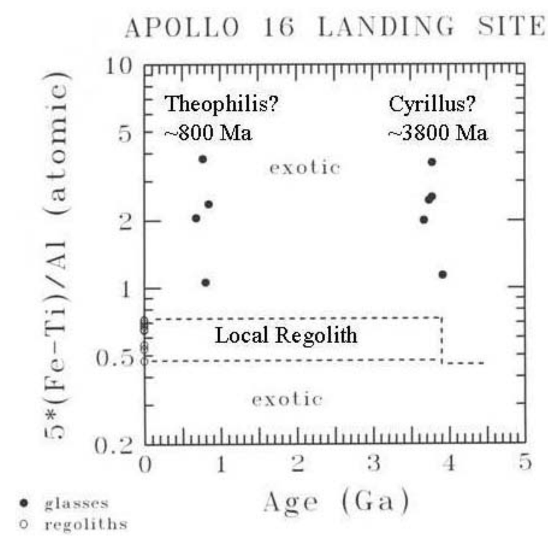

Figure 2. Age distribution of 9 impact glasses from 64501.