APOLLO 14 IMPACT GLASSES AND CLEMENTINE DATA: IMPLICATIONS FOR REGIONAL GEOLOGY. N. E. B. Zellner[1], P. D. Spudis[2], J. W. Delano[3], and D. C. B. Whittet[1], [1]New York Center for Studies on the Origin of Life, Rensselaer Polytechnic Institute, Troy, NY 12180 zellnn@rpi.edu, [2]Lunar and Planetary Institute 3600 Bay Area Blvd., Houston, TX 77058, [3]New York Center for Studies on the Origin of Life, Department of Earth and Atmospheric Sciences, University at Albany (SUNY), Albany, NY 12222.

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. 778 glasses from the Apollo 14 landing site have been analyzed by electron microprobe in this study. These glasses show significant variation and hint at the existence of multiple terrains of differing compositions near the landing site. 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 highlands in the Fra Mauro region of the Moon consist of a KREEP-rich regolith overlying a more feldspathic terrain. These results illustrate how lunar impact glasses and orbital data can provide geochemical constraints on the local and regional geology of the Moon [1,2].

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 [3]. 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 [4,5], this study uses orbital data to show that glass composition(s) most often represent regolith composition(s).

The Apollo 14 Landing Site: Apollo 14 was sent to sample the Fra Mauro Formation, which is interpreted to be dominated by Imbrium ejecta. Ridges of the Fra Mauro Formation are roughly radial to the Imbrium Basin and were probably formed by material flowing along the ground during excavation of the basin [6,7]. Cone Crater, which is on top of one of the ridges, may have penetrated the KREEP-rich regolith into an underlying, more feldspathic terrain [2,6]. Although orbital data [1,2,8] show that the surface of the Apollo 14 region is KREEP-rich, several outcrops of feldspathic material are seen on crater rims [2].

Sample Analysis: 151 impact glasses from Apollo 14 regolith 14259 have been analyzed by electron microprobe for the elements Si, Ti, Al, Cr, Fe, Mn, Mg, Ca, Na, and K. We have compared these glasses with 627 impact glasses in regolith breccias from the Apollo 14 landing site (i.e. 14313, 14307, 14301, 14049, 14047), which represent ancient regoliths in the region [9]. Since these breccias appear to have formed at different times [9], these breccias have different populations of glasses that provide temporal constraints on the addition of components to the regolith.

Major-element analyses of the lunar glasses were performed with on-line data reductions using a JEOL 733 electron microprobe in the Department of Earth and Environmental Sciences at Rensselaer. Five X-ray spectrometers were tuned and calibrated for each element that was being 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 this 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.

Results: Analyses of impact glasses from the 14259 regolith and 5 regolith breccias are shown in Figures 1 and 2. These plots show that impact glasses from the Apollo 14 site comprise at least two compositional groups. The most populous group is a diffuse cluster of glasses that plots in the left-of-center portion of the ternary diagram, which is equivalent to the KREEPy regolith at the Apollo 14 site.

The second most populous cluster of glass compositions is both less KREEP-rich and more aluminous than the previous group. This cluster is identified by the arrow in Figure 1. These glasses have the composition of "highland basalt" [4,5]. Although these Apollo 14 highland basalt glasses bear a resemblance to the Apollo 16 regolith, they most closely resemble the regolith breccias represented by the lunar highland meteorites (e.g. ALHA81005, MAC88105). Compositional trends in this group show mixing towards even more feldspathic components.

The highland basalt glasses from sample 14259 have counterparts in the Apollo 14 regolith breccias (Figure 2). The distribution of compositional glass groups in Figure 2 mimics the pattern seen in Figure 1. A tight cluster of glasses, identified by the arrow, is prominent in regolith breccia 14047, possessing the same composition as the highland basalt glasses seen in regolith 14259. Since 14047 is the youngest of the 5 breccias examined [9], the prominent occurrence of these glasses indicates that the numbers of highland basalt glasses at the surface of the Apollo 14 region may have been "recently" and significantly increased.

Conclusions: Although we cannot yet be certain, we suggest that the highland basalt glasses at the Apollo 14 landing site are derived from pre-Imbrium regolith that underlies the KREEP-rich regolith. If the total thickness of Imbrium ejecta is relatively thin at this distance from Imbrium, it is possible that the highland basalt glasses have pre-Imbrium ages and were exhumed by a recent cratering event, such as the Cone Crater event [2,6]. In this scenario, Cone penetrated the KREEP-rich Fra Mauro Formation and excavated feldspathic, highland basalt regolith from beneath the Imbrium ejecta.

The highland basalt impact glasses may be pre-Imbrium in age and may provide insights into the evolutionary history of the lunar regolith, both by providing evidence for the composition of the ancient lunar surface and by providing an isotopic record of impact events that may have occurred prior to 3.9 Ga ago, the time of the proposed "lunar cataclysm" [e.g. 10,11]. Analysis of these KREEP-poor glasses may provide evidence for impacts occurring before KREEP-rich (Imbrium) material was delivered to the surface. If our hypothesis is correct, the ages of these highland basalt glasses will have an interesting story to tell about the impact flux in the Earth-Moon system.

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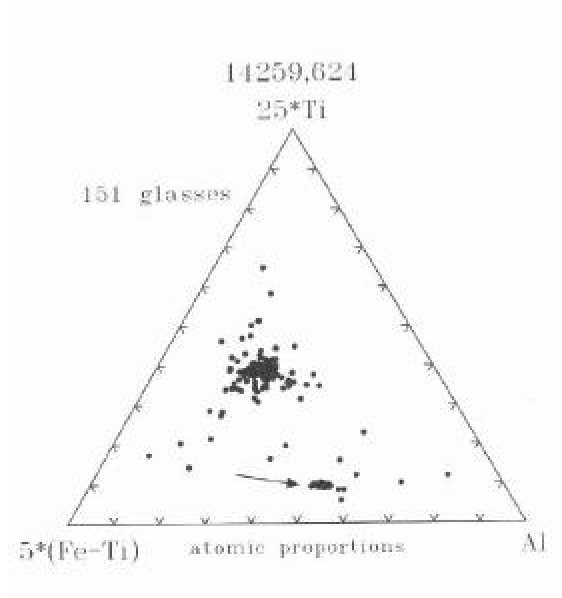

Figure 1. Glass compositions (151) from regolith 14259. The highland basalt glasses are identified with an arrow. The coordinates of the ternary diagram represent the atomic proportions of the non-volatile elements analyzed in the lunar impact glasses and can be used to describe the chemical and mineralogical nature of the original target materials [3].

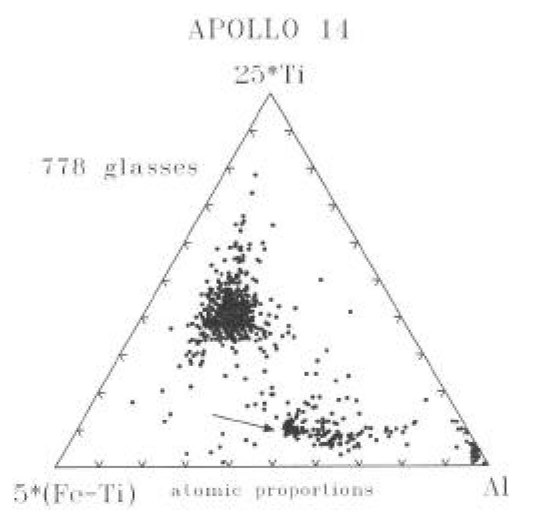

Figure 2. Glass compositions (778) from regolith 14259 and 5 regolith breccias (14047, 14049, 14301, 14307, 14313). The highland basalt glasses are identified with an arrow.