EXPLORING NON-UNIFORM ^{40}Ar* LOSS IN APOLLO 16 IMPACT MELT BRECCIAS USING A LASER MICROPROBE. C. M. Mercer[1,*], K. V. Hodges[1], and M. C. van Soest[1], [1]School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287 ([*]E-mail: cameron.m.mercer@asu.edu)

Introduction: The timing of major melt-forming impact events on the Moon is primarily quantified through isotope geochronology of impact melt products in lunar meteorites and samples returned by the Apollo and Luna missions (e.g., [1-3]). The ^{40}Ar/^{39}Ar method in particular has proven to be a valuable tool to date lunar impactites because the K-Ar isotopic system can be partially or fully reset by the high-temperature conditions of impact events (e.g., [1, 4-6]). Rocks that melt entirely during impact and subsequently quench or rapidly crystallize are the most likely to have their K-Ar systematics fully reset, and should ideally have flat release spectra in incremental heating ^{40}Ar/^{39}Ar experiments. Rocks that cool slowly, or that experience post-formational diffusive argon loss, typically have incremental release spectra characterized by younger apparent ages at low experimental temperatures and older apparent ages at intermediate to high experimental temperatures. In cases where three or more contiguous steps (representing at least 50% of the gas released) have the same apparent age (within 2σ), a plateau date is often interpreted as the formation age of the sample. Only the minimum age of a sample can be constrained in cases of extreme partial argon loss. On the Moon, there are a few major mechanisms that can cause partial argon loss in surface and near-surface rocks. These include reheating by (1) igneous activity (e.g., in contact aureoles), (2) one or more impacts (e.g., [5, 7]), and (3) diurnal heating of rocks at the lunar surface (e.g., [8, 9]).

We used an ultraviolet laser ablation microprobe (UVLAMP) system to extract gas for ^{40}Ar/^{39}Ar analysis from the Apollo 16 impact melt breccias (IMBs) 60315, 61015, and 63355. Published ^{40}Ar/^{39}Ar release spectra for samples 60315 and 61015 exhibit the low-T characteristics expected for partial diffusive loss of argon, and their reported plateau dates are 3901 ± 16 Ma and 3932 ± 18 Ma, respectively [10] (uncertainties are 2σ). (These dates were recalculated using *ArAR* [11] to use the MMhb-1 age of Renne et al. [12] rather than that of Lanphere et al. [13].) To the best of our knowledge, no incremental heating ^{40}Ar/^{39}Ar data have been published for 63355.

By studying these samples with the UVLAMP technique, we can better understand how evidence for partial argon loss is manifested in a population of total fusion spot analyses. It is important to note that these samples are generally fine grained, with typical grain diameters between a few to a few tens of μm, which is much smaller than the size of the UV laser beam. The UVLAMP spot fusion data therefore reflect the gasses released from polymineralic mixtures of materials with a range of diffusive characteristics.

Experimental and Analytical Methods: Sample preparation and characterization methods were similar to those of Mercer et al. [7]. Roughly 9 mm x 9 mm sections of samples 60315, 61015, and 63355 were irradiated for 115 hours in the CLICIT facility of the OSU TRIGA research reactor. We used a New Wave Research *UP193X* ArF 193 nm excimer laser to ablate ~80-180 μm diameter pits with average depths of ~20-40 μm in the irradiated sections. Gasses evolved from ablation were purified and Ar isotopes were analyzed using a Nu Instruments *Noblesse* mass spectrometer.

Data were corrected for detector baselines, operational blanks, mass bias, interfering isotopes produced during irradiation, the decay of ^{37}Ar and ^{39}Ar following irradiation, and cosmogenic isotopes produced in the lunar environment. We calculated ^{40}Ar/^{39}Ar model dates relative to the PP20 age monitor (1078.9 ± 4.6 Ma, 1σ [9]) assuming ^{40}Ar/^{36}Ar = 1 ± 1 (1σ) for trapped lunar argon, and used the ^{40}K decay constants of Steiger and Jäger [14].

Results: The studied section of 60315 (60315,235) has a poikilitic texture dominated by oikocrysts of orthopyroxene (opx) that enclose laths and clasts of plagioclase (plag). Section 61015,197 was prepared from the melt component of 61015 (a dimict breccia), and has a very fine-grained intersertal texture of plag and olivine, with a glassy mesostasis in the interstices and fractures. The melt in section 63355,65 has a poikilitic texture dominated by oikocrysts of opx enclosing plag laths, and ilmenite and glass is common between oikocrysts. Section 63355,65 also contains large clasts of norite and anorthosite.

Model dates for individual UVLAMP analyses of melt components range from ca. 3912-3541 Ma for 60315, from ca. 3863-3458 Ma for 61015, and from ca. 3469-789 Ma for 63355. We specifically targeted regions in 61015 with abundant glassy mesostasis, and found that those analyses had generally lower apparent ages and Ca/K ratios between ca. 48-112. While the ^{40}Ar/^{39}Ar dates for 60315 do not show any particular correlation with Ca/K ratio, plots of apparent age versus Ca/K for 61015 and 63355 may indicate multi-component mixing (Fig. 1). UVLAMP ^{40}Ar/^{39}Ar dates of relict clasts are generally older than or the same age as the melt, and commonly have higher Ca/K ratios.

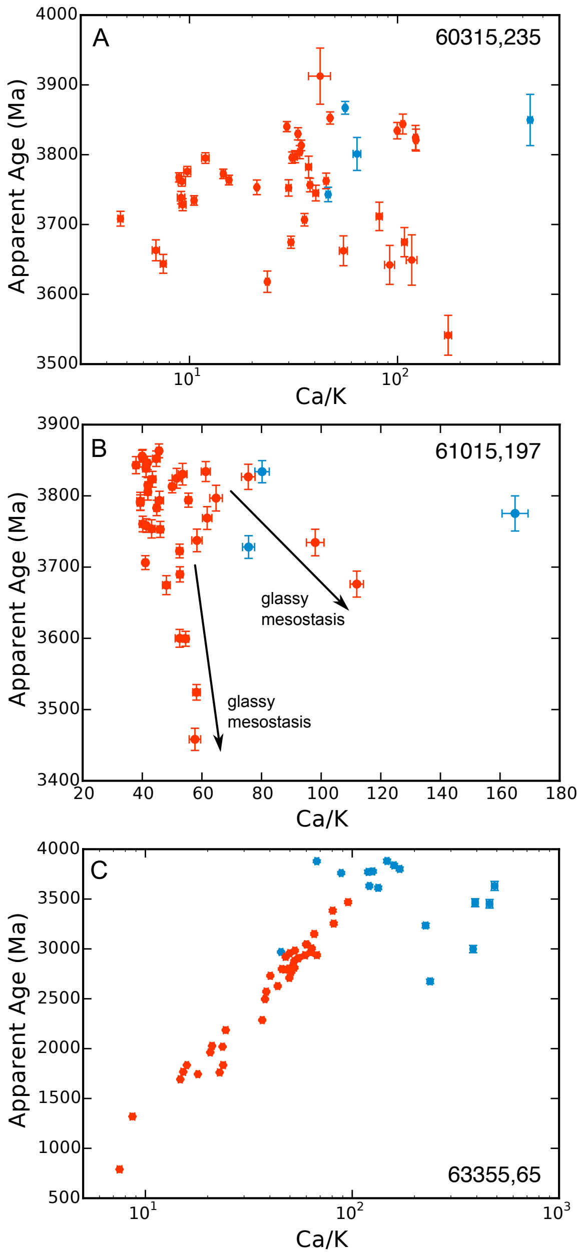

Figure 1. Plots of apparent age vs. Ca/K ratio for individual UVLAMP $^{40}Ar/^{39}Ar$ analyses in (A) 60315,235, (B) 61015,197, and (C) 63355,65 (note the semi-log scales in panels A and C). Red markers denote analyses of melt components, and blue markers denote analyses of relict clasts. Error bars are 2σ.

Discussion: All three samples studied here have highly dispersed populations of UVLAMP $^{40}Ar/^{39}Ar$ dates, likely reflecting post-formation partial diffusive loss of argon. The youngest low-T steps reported by Norman et al. [10] for 60315 and 61015 had apparent ages of 1917 ± 24 Ma and 2438 ± 17 Ma, respectively (2σ). The oldest reported steps for 60315 and 61015 had apparent ages of 3921.3 ± 9.0 Ma and 4230 ± 440 Ma (2σ), respectively [10]. Our UVLAMP data span a smaller range of apparent ages for both 60315 and 61015. The oldest spot fusion dates tend toward the published plateau dates, especially for 60315,235, but the youngest spot fusion dates are not as young as the youngest reported low-T steps. For 61015, the glassy mesostasis is clearly the phase that is least retentive of argon. Because it is so pervasive throughout the sample, we likely did not avoid it completely during ablation. This may explain why the oldest spot fusion date is not quite as old as the published plateau date.

The UVLAMP $^{40}Ar/^{39}Ar$ dates of melt in 63355 are strongly correlated with the Ca/K ratio of ablated materials. Furthermore, the relation is logarithmic, suggesting a simple two-component mixture between two $^{40}Ar^{*}/^{39}Ar_K$ reservoirs (one older, and one younger). There may be a distinctive, probably glassy, K-rich phase that is less retentive of argon than other components of the melt, as has been suggested previously for other lunar samples (e.g., [5, 15]).

Our results have three important implications. First, partial diffusive loss of argon commonly yields highly dispersed datasets of spot fusion $^{40}Ar/^{39}Ar$ dates that are consistent with the range of apparent ages observed in conventional incremental release spectra. Secondly, the oldest spot fusion dates serve as good estimates of the minimum ages of samples that have experienced partial argon loss, and in some cases they can be indistinguishable from published plateau dates. Thirdly, partial diffusive loss of argon is commonly nonuniform; this implies that low-retentivity materials are not uniformly distributed throughout the samples at sufficiently small spatial scales to be undetectable by the UVLAMP technique. Collectively, these observations reaffirm that the UVLAMP technique is a valuable tool that can complement conventional $^{40}Ar/^{39}Ar$ methods in analyzing extraterrestrial materials.

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