DIVERSE IMPACT HISTORIES OF APOLLO 17 MELT BRECCIAS REVEALED BY *IN SITU* ^{40}Ar/^{39}Ar GEOCHRONOLOGY.

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Introduction: The timing of impact events on the Moon can be determined quantitatively by radiometrically dating impact glasses or neoblastic minerals in recrystallized impact melts. The ^{40}Ar/^{39}Ar method has been widely employed to study the thermal histories of lunar meteorites and samples returned by the Apollo and Luna missions, though interpretations of impact ages can be complicated by the presence of inherited, incompletely reset materials, or of multiple generations of impact melts, e.g., [1-4]. The application of high-spatial resolution, *in situ* analytical techniques may alleviate these difficulties, allowing potential contaminating phases to be avoided and distinct age domains to be resolved.

We utilized an ultraviolet laser ablation microprobe to acquire numerous *in situ* ^{40}Ar/^{39}Ar dates in sections of two Apollo 17 impact melt breccias. Sample 77115 is a "blue-grey" breccia that was collected from the Station 7 boulder at the base of the North Massif. Interestingly, the rock unit represented by 77115 was observed in the field to be continuous with dark veinlets (sample 77075) that crosscut a large noritic clast in the boulder [5], but ^{40}Ar/^{39}Ar dates of 77075 are ~50-70 Ma older than those reported for 77115 [6-8].

Sample 73217 is a polymict breccia collected at Station 3 from the rim of an unnamed 10 m diameter crater in the landslide material at the base of the South Massif. U/Pb dates of apatite, merrillite, and three distinct morphological types of zircon grains in 73217,52 were interpreted by Grange et al. [9] to represent two impact events at 4335 ± 5 Ma and 3934 ± 12 Ma (95% confidence). To the best of our knowledge, no ^{40}Ar/^{39}Ar data have been published for 73217.

Methods: New polished thick-sections 77115,121 and 73217,83 were prepared at NASA Johnson Space Center for *in situ* ^{40}Ar/^{39}Ar analyses along with facing thin-sections 77115,122 and 73217,84 for supporting petrographic observations. We obtained backscattered electron (BSE) image mosaics for all sections, and X-ray chemical maps were made for the thin-sections using the JEOL JXA-8200 electron microprobe at Washington University in St. Louis. Following petrologic characterization, we separated ~9x9 mm pieces from the thick-sections for neutron irradiation at the McMaster University Reactor, Hamilton, Canada.

We employed a New Wave Research *UP193X* ArF 193 nm excimer laser to ablate ~70-200 μm diameter pits with average depths of ~16-38 μm in the irradiated sections. Pit locations were determined with reference to the BSE and X-ray chemical maps to target glassy and recrystallized impact melt separately from inherited xenocrystic and xenoclastic material within distinct petrographic domains. Gasses evolved from ablation were purified and Ar isotopes were analyzed using a Nu Instruments Noblesse mass spectrometer.

Data were corrected for detector baselines, measurement blanks, mass discrimination, interfering isotopes produced during irradiation, the decay of ^{37}Ar and ^{39}Ar following irradiation, and cosmogenic isotope production in the lunar environment. We calculated ^{40}Ar/^{39}Ar dates relative to the PP20 age monitor (1078.9 ± 4.6 Ma, 1σ; recalculated from Jourdan et al. [10] using the Fish Canyon sanadine age of Kuiper et al. [11]), and used the ^{40}K decay constants of Steiger and Jäger [12].

Sample Descriptions: Thick-section 77115,121 is a fine-grained, recrystallized-impact melt breccia with abundant mineral and lithic fragments. The K_2O content of the melt ranges between ~0.2-0.4 wt%. The thick section 73217,83 is complex, with four lithologic domains: (1) a very fine-grained, clast-poor impact melt breccia with a K-bearing mesostasis; (2) a coarser, clast-rich impact melt-bearing breccia with a potassic glassy matrix; (3) a fine-grained, plagioclase-rich recrystallized melt breccia; and (4) a coarse gabbroic granulite. The bulk K_2O contents of the mesostasis and the glassy matrix of lithologies 1 and 2 are typically between 2-2.5 wt% and 4-5 wt%, respectively.

^{40}Ar/^{39}Ar Results: We acquired 26 dates from 77115,121 (Fig. 1); 15 are from laser pits in recrystallized impact melt and 11 are from pits that were ablated wholly in inherited mineral and lithic clasts or included clastic material at depth that was not visble at the surface prior to ablation. The error weighted means of the melt and clast dates are 3826 ± 22 Ma (2σ) and 3890 ± 15 Ma (2σ), respectively, and the error weighted mean of all 26 dates is 3849 ± 19 Ma (2σ).

We measured 63 impact melt dates from 73217,83 (Fig. 2) from Areas 1, 2, and 3. The K_2O content of gabbroic clast (Area 4) is so low that we could not liberate enough Ar gas to determine a precise date. Since none of the populations of dates for Areas 1-3

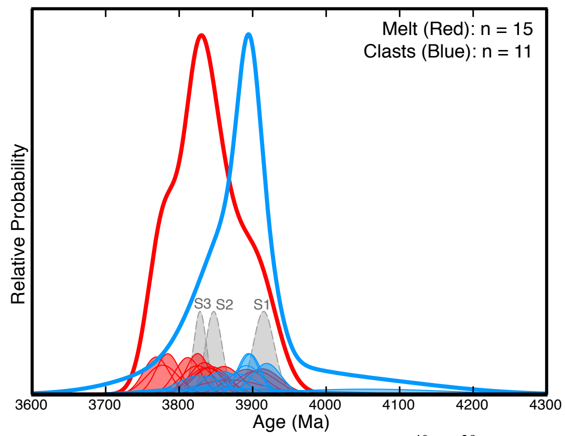

Figure 1. Probability density plot of our $^{40}Ar/^{39}Ar$ dates (colored solid curves) from 77115,121, and the weighted means of previously published $^{40}Ar/^{39}Ar$ data (grey dashed curves) for 77075 (S1, n = 3) [6, 8], 77115 (S2, n = 2), and 77135 (S3, n = 5) [7, 8]; see text for dates.

are perfectly unimodal, we employed the methods of Sambridge and Compston [13] and Galbraith [14] to identify the best model dates for the dominant modes for each population (labeled 1A, 1B, 2, and 3 in Fig. 2). These are: (1A) 3271 ± 22 Ma; (1B) 3620 ± 11 Ma; (2) 3660 ± 11 Ma; and (3) 3812.7 ± 8.2 Ma (uncertainties reported as 2 standard errors; *n* given in Fig. 2 for each population).

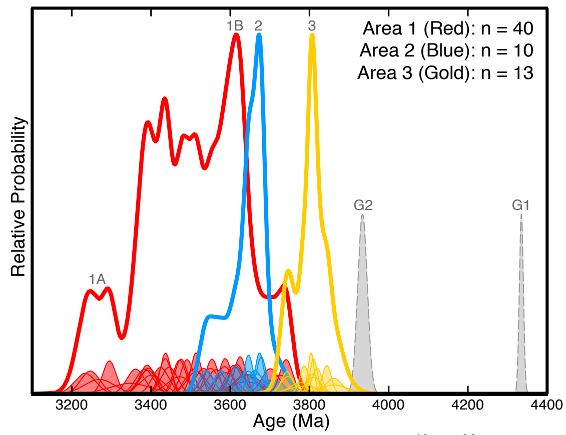

Figure 2. Probability density plot of our $^{40}Ar/^{39}Ar$ dates (colored solid curves) from 73217,83, and U/Pb dates (grey dashed curves, G1 and G2 [9]) from 73217,52.

Discussion: Using the laser microprobe, we were able to effectively obtain a population of $^{40}Ar/^{39}Ar$ dates that are representative of the melt in 77115,121, and avoid contamination by relict, incompletely reset materials. Thus, the simplest interpretation of our data is that the impact event that formed 77115 occurred at 3826 ± 22 Ma (2σ).

Interestingly, the error weighted means of the plateau dates reported by Stettler et al. [6-8] for 77075, 77115, and 77135 (S1, S2, and S3, Fig. 2) are 3915 ± 24 Ma, 3847 ± 22 Ma, and 3828 ± 17 Ma, respectively (2σ uncertainties; dates recalculated using the decay constants and isotopic abundance values of Steiger and Jäger [12]). The weighted mean of our clast dates overlaps significantly with the age of 77075, the combined date of all of our laser pits is identical to that reported for 77115, and the weighted mean date of our melt pits is identical to the published age of 77135.

The nearly 70 Myr difference between 77075 and 77115 puzzled Stettler et al. [7, 8] since the two rocks are continuous in the Station 7 boulder. Thus, they proposed that 77115 and 77075 were formed and emplaced simultaneously, and subsequently 77115 was severely outgassed during the emplacement of 77135 while 77075, which is located farther from the contact with 77135, remained unreset [8]. While this is a complex scenario, our data are not necessarily inconsistent with it. In fact, since our "melt" date of 3826 ± 22 Ma (2σ) is identical to the age of 77135, it is possible that the dates for 77115 reported by Stettler et al. [7, 8] were affected by the presence of inherited material.

Sample 73217,83 exhibits a complex and extended impact record, and the three petrographic regions we analyzed each preserve distinct thermal histories. In the simplest case, the major peaks labeled 1A, 1B, 2, and 3 in Fig. 2 could be interpreted to represent distinct impact events. In particular, events 1B, 2, and 3 likely reflect the formation age of the melt in each lithology, while event 1A represents the minimum age of a later event that partially degassed material in Area 1, and possibly some in Area 2 (assuming the breccia had been assembled before 1A occurred).

Because the U/Pb isotopic system is more resistant to thermal resetting than the K-Ar system, the U/Pb dates reported by Grange et al. [9] for 73217,52 (G1 and G2, Fig. 2) reflect older impact events (at 4335 ± 5 Ma and 3934 ± 12 Ma, 95% confidence) than those we observe in our $^{40}Ar/^{39}Ar$ data. Thus, the combined datasets imply that 73217 records up to six impact events spanning a period of nearly 1.1 billion years.

References: [1] G. Turner, P. H. Cadogan (1975) *LPSC* VI, 1509–1538. [2] P. Maurer et al. (1978) *GCA*, 42, 1687–1720. [3] G. B. Dalrymple, G. Ryder (1996) *JGR*, 101, 26069–26084. [4] M. D. Norman et al. (2006) *GCA*, 70, 6032–6049. [5] H. H. Schmitt (1973) *Science*, 182, 681–690. [6] A. Stettler et al. (1974) *EPSL*, 23, 453–461. [7] A. Stettler et al. (1975) *LPSC* VI, 771–773. [8] A. Stettler et al. (1978) *LPSC* IX, 1113–1115. [9] M. L. Grange et al. (2009) *GCA*, 73, 3093–3107. [10] F. Jourdan et al. (2006) *Chem. Geo.*, 231, 177–189. [11] K. F. Kuiper et al. (2008) *Science*, 320, 500–504. [12] R. H. Steiger, E. Jäger (1977) *EPSL*, 36, 359–362. [13] M. S. Sambridge, W. Compston (1994) *EPSL*, 128, 373–390. [14] R. F. Galbraith (1988) *Technometrics*, 30, 271–281.