VOLCANIC EVENTS AT THE APOLLO 15 LANDING SITE: ERUPTION AGES FROM OLD TO YOUNG N. E. B. Zellner[1], M. D. Norman[2], F. Jourdan[3], [1]Department of Physics, Albion College, Albion, MI USA 49224, [2]Research School of Earth Sciences, Australian National University, Canberra ACT 0200 Australia, [3]Western Australian Argon Isotope Facility, Department of Applied Geology and JdL Centre, Curtin University, Perth, Australia.

Introduction: The compositions and ages of lunar volcanic glasses have been used to investigate episodes of lunar volcanic fire fountaining and the timing of those episodes. Here we present new major- and trace-element compositional data and ages for volcanic glasses from Apollo 15 regolith sample 15221, updating previous work [1]. An age of 3592 ± 18 Ma from yellow volcanic glasses gives a more precise timing of the formation of these picritic glasses, while an age of 2839 ± 90 Ma gives a younger eruption age than has been documented previously for a subset of the green glasses.

Background: The Apollo 15 landing site is on the eastern margin of the Imbrium Basin and was selected so that the Apennine Front and the eastern rim of Hadley Rille could be examined. It was expected that material from deep in the lunar crust could be found on the rim of the Imbrium Basin, along the Apennine Mountains, while Hadley Rille, a channel in the mare surface, would offer opportunities to learn about volcanic processes.

Numerous studies of the Apollo 15 green and yellow volcanic glasses have revealed discrete compositional groups, with Mg-numbers ranging from 60 to 67 [2-5]. Explanations for this variation include mixing between magma and olivine [5] and mixing between two contemporaneous, but chemically distinct, magmas [2]. A recent study [6] using KREEP basalts collected at the Apollo 15 site has investigated the range in magma compositions represented by these samples.

Analyses: Major- and trace- element analyses on 83 volcanic glasses from Apollo 15 regolith 15221,21 were undertaken at the Australian National University between 2011 [17] and 2013. Two subsets of glasses were subsequently irradiated for 40 hours and analyzed for multiple Ar isotopes, including ^{40}Ar and ^{39}Ar. Laser step-heating on these samples was carried out in Fall 2012 and Fall 2016 at the Western Australia Argon Isotope Facility at Curtin University [1].

Discussion: Compositions based on major elements and ^{40}Ar/^{39}Ar ages for volcanic glasses from 15221 are shown in Table 1. The MgO/Al_2O_3 values for each of the yellow and green volcanic glasses are consistent with previous analyses. Delano [2, 19] determined that these yellow glasses with MgO/Al_2O_3 ~1.5 represent a magma or a series of three magmas that formed at a depth of ~480 km while the green glasses (MgO/Al_2O_3 ~ 2.5) represent five magmas that formed at a depth of ~400 ± 50 km. Figure 1 shows the FeO vs. TiO_2 distribution of these glasses; the distinction between low-Ti and very-low Ti (VLT) volcanic glasses is consistent with previous studies [3, 4]. Although eruption ages of most mare basalt groups are well-established [15, 16], uncertainty remains in the eruption ages of the volcanic glasses. As seen in Table 1, ^{40}Ar/^{39}Ar eruption ages of the green and yellow volcanic glasses differ depending on the amount of TiO_2 in the sample. In general, the ^{40}Ar/^{39}Ar eruption ages for these 15221 samples range from ca. 3300 to 3700 Ma [e.g., 11-14] and are consistent with the ^{87}Rb/^{87}Sr and/or ^{147}Sm/^{143}Nd ages of the local crystalline mare basalts [15,16], with a few exceptions.

Low-Ti Glasses: The low-Ti yellow glasses yielded more precise ^{40}Ar/^{39}Ar data with four plateau ages ranging from 3521 ± 77 to 3628 ± 67 Ma. Assuming that these ages reflect a single eruption as suggested by their composition and by the similarity of ages, we can calculate a weighted eruption age of 3592 ± 18 Ma for the low-Ti glasses, from a depth of ~480 km [19].

VLT Glasses: Dominated by solar wind (i.e., high ^{40}Ar/^{36}Ar values) and having low K_2O concentrations, the ultramafic green glasses from 15221 were difficult to date. N02 yielded an ^{40}Ar/^{39}Ar plateau age of 3290 ± 89 Ma, consistent with previous values [e.g., 14]. Three glasses, however, with similar trace element compositions (Figure 2), have a weighted mean age of 2839 ± 90 Ma, ~500 Ma younger than has been previously measured for the Apollo 15 green volcanic glass eruptions. This may be an actual eruption age or the result of argon loss due to how much time these glasses rested on the lunar surface. Argon retentivity has been shown to depend on X(NBO), (i.e., non-bridging oxygens; [7-9]), with lunar picritic volcanic glasses having $0.39 \leq X(NBO) \leq 0.60$ [e.g., Apollo 15 green A = 0.598; Apollo 15 yellow = 0.524; 10]. We note that this younger age is consistent with interpretations of young mare areas via crater size-frequency measurements using high-resolution images obtained by the SELENE Terrain Camera [25].

Conclusion: Our new ^{40}Ar/^{39}Ar age of 3592 ± 18 Ma provides a more precise age for the eruption of the yellow volcanic glasses compared to previous measurements of ~3.62 Ga, with no uncertainty quoted [14]. An age of ~3300 Ma for the eruption of the green volcanic glasses is consistent with previous studies, but there appears to be a younger subset of green volcanic glasses with an age ~2800 Ma. In general, the ages of the volcanic glass eruptions are consistent with older

glasses (i.e., the yellow volcanic glasses) coming from deeper in the lunar interior than the younger glasses (i.e., the green volcanic glasses).

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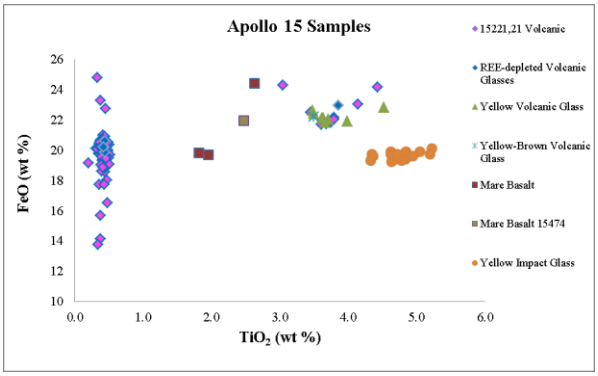

Figure 1. Apollo 15 (15221) volcanic glasses with a range of TiO2 (wt %) plotted with other Apollo 15 samples [14, 21-24].

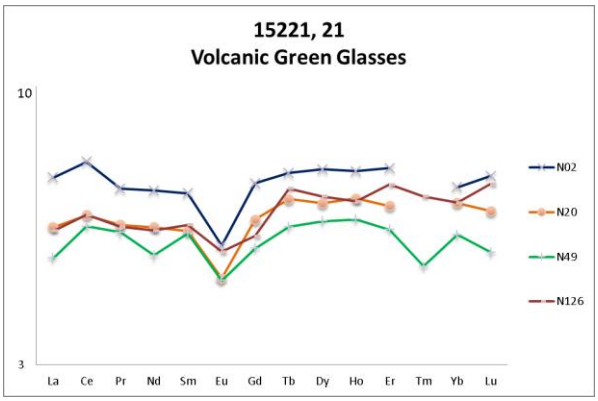

Figure 2. Trace elements, normalized to chondritic [20] for 4 green volcanic glasses from sample 15221 with well-defined $^{40}Ar/^{39}Ar$ ages (Table 1).

Table 1. Shape, size, composition, and age data for green and yellow volcanic glasses from 15221. Color is "y" for yellow, "g" for green, and "r" for red. F is fusion age; ND is not determined.

Sample (color)	Shape Size (μm)	TiO_2 (wt %)	MgO/Al_2O_3	$^{40}Ar/^{39}Ar$ Age (Ma)
N12 (y)	sphere 250	3.75	1.32	3521±77
N16 (y)	sphere 500	3.68	1.45	3591±21
N32 (y)	sphere 250	3.71	1.63	3628±67
N39 (y)	shard 300×221	3.62	1.52	3618±105
N40 (r)	oblong 350×260	3.63	1.41	3630±51
N68 (r)	dumbbell 550×270	4.14	1.36	3519±56
N112 (r)	shard 450×455	3.86	1.42	2730±233 (F)
N02 (g)	sphere 470	0.45	2.34	3290±89
N20 (g)	oblong 300×200	0.43	2.29	2838±254
N49 (g)	sphere 140	0.45	2.52	2835±276
N126 (g)	Shard 160×125	0.33	2.36	2830±126
N47 (g)	½ dumbbell (ND)	0.38	2.45	1653±1482 (F)
N45 (g)	½ dumbbell 275×130	0.43	2.10	39±2432 (F)