TRAPPED ^{40}AR/^{36}AR CLOSURE AGES OF APOLLO 15 REGOLITH SAMPLES LITHIFIED OVER THE PAST 3 BILLION YEARS. Amy L. Fagan[1,2], Katherine H. Joy[1,2,3], and David A. Kring[1,2]. [1]Center for Lunar Science and Exploration, The Lunar and Planetary Institute, 3600 Bay Area Boulevard, Houston, TX 77058, USA; [2]NASA Lunar Science Institute, (Fagan@lpi.usra.edu); [3]School of Earth, Atmospheric and Environmental Sciences, University of Manchester, Williamson Building, Oxford Road, Manchester, M13 9PL, UK.

Introduction: Regolith breccias contain a record of pre-existing geologic processes, including impact cratering events that shaped the lunar surface. It was recently shown [1] that Apollo 16 ancient regolith breccias contain relic fragments of the impactors hitting the Moon >3.4 Ga. A younger set of breccias and soils with impactor relics was also found at that site [1]. Those samples were collected from the Cayley Formation and produced after the Imbrium basin-forming event, in part from debris emplaced ~1000 km from Imbrium. In this work, we turn our attention to the Apollo 15 site, which is located near the rim of the Imbrium basin, to determine if a similar set of impactor relics are preserved there.

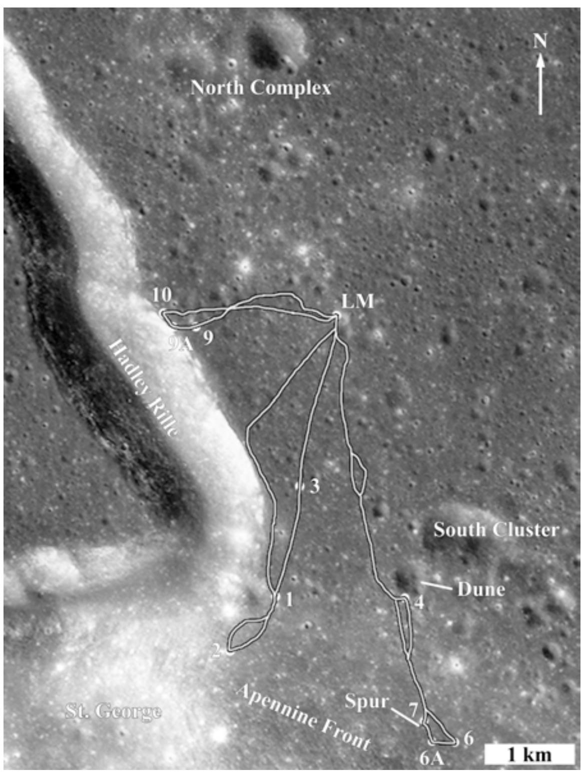

Figure 1. Apollo 15 traverse and station map over a portion of LROC NAC image M106855508L (Image: NASA/GSFC/ASU).

Apollo 15 Geologic Context: The Apollo 15 Lunar Module (LM) landed on a mare plain at the eastern margin of the Imbrium basin (26.13°N, 3.63°E [2]; Fig. 1). Two EVAs ventured to the Apennine Front, which is part of the bounding massifs of Imbrium, where fine-grained, cratered regolith (e.g., [3]) was sampled from stations 2, 6, 6A and 7. Regolith near Hadley Rille, the subject of the 3rd EVA, was sampled at stations 9A, and 10 (Fig. 1). The LM site, along with stations 1, 3, 4 and 9 are located within the mare plain, which is bounded by Hadley Rille, the Appenine Front, and the North Complex (Fig. 1). Soil samples at all stations typically contain more glass than the regolith breccias [4]. Regolith breccias from station 6 generally have higher abundances of agglutinates and station 7 samples have higher concentrations of glass spheres than other stations [4]. Despite their collection along the Apennine Front, most regolith breccias from stations 6 and 7 contain some mare basalt, KREEP basalt, or both [4].

Closure Age Calculation Method: The trapped ^{40}Ar/^{36}Ar ratio (^{40}Ar/^{36}Ar$_{Tr}$) in a regolith breccia can be used to determine the time of breccia lithification (e.g., [5-8]). That system was recently recalibrated [9], producing the formula: $t=1.2103\ln(^{40}Ar/^{36}Ar_{Tr})+0.7148$, in which t is the sample lithification age (Ga). Using this new calibration, we have re-calculated the closure ages of 25 regolith breccias (Table 1) and 13 soil samples from the Apollo 15 mission.

Results: Calculated closure ages for the Apollo 15 regolith breccias range from 0.02 to 2.65 Ga. The Apollo 15 soils [10-14] are generally 0.2 to 1.2 Ga in age with the exception of four samples generating slightly negative ages (-0.6 to -0.2 Ga); this may indicate that the calibration is insufficient for characterizing the youngest samples. Our focus, however, is on older samples.

Table 1. ^{40}Ar/^{36}Ar$_{Tr}$ & closure ages of Apollo 15 Regolith Breccias.

Sample	I_s[1]/FeO	^{40}Ar/^{36}Ar$_{Tr}$[2]	Age[3] (Ga)	Sample	I_s[1]/FeO	^{40}Ar/^{36}Ar$_{Tr}$[2]	Age[3] (Ga)
15015,167	3	0.85	0.52	15298,59	59	0.70	0.29
15026,6	68	0.56	0.02	15299,205	32	0.77	0.40
15028,10	26	0.62	0.13	15426,126	0	4.94	2.65
15059,231	36	0.87	0.54	15427,71	24	3.99	2.39
15086,97	19	1.53	1.23	15459,226	25	3.87	2.35
15245,118	41	1.28	1.01	15465,89	12	2.75	1.94
15257,7	21	1.29	1.02	15467,5	9	3.23	2.14
15265,66	23	1.68	1.34	15498,126	18	1.66	1.33
15266,23	14	1.71	1.36	15505,91	26	0.58	0.06
15268,8	32	1.78	1.41	15528,7	21	1.89	1.48
15286,42	13	1.45	1.17	15558,33	21	1.40	1.12
15287,10	28	2.39	1.77	15565,117	19	2.31	1.73
15295,30	38	1.07	0.79				

[1]Maturity indicator data from [4]; [2]We corrected the ^{40}Ar/^{36}Ar ratios of McKay et al. [4] to calculate the ^{40}Ar/^{36}Ar$_{Tr}$ by employing (i) the radiogenic ^{40}K decay to ^{40}Ar [16] using the bulk K-concentration of the sample (when unavailable, the K-concentration was taken as that of the surrounding soil following the method of [4]); and (ii) an assumed age of ~ 3.4×10^9 years [4]. [3]Calculated from Eqn. 6 in [9]).

Age correlation. The Apollo 15 regolith breccias generally have younger closure ages than the Apollo 16 regolith breccias [9] (Fig. 2a). At least nine of the Apollo 16 regolith breccias likely formed >3 Ga ("ancient"), seven formed 2 to 3 Ga ("young"), and one has a closure age ~1.7 Ga ("soil-like"). In contrast, none of the Apollo 15 regolith breccias examined here likely formed >3 Ga, and most have closure ages 1 to 2 Ga. This is not wholly unexpected, as the mare beneath the surface of the Apollo 15 site from whence the regolith and subsequent regolith breccias are derived is ~3.3 Ga [15]. Similarly, the Apollo 15 soils (Fig. 2a) have younger 'appearance ages' (see discussion in [9]), with only one sample forming >1 Ga; in contrast, 23 (of 40) Apollo 16 soil samples have ages >1 Ga.

Maturity correlations. All of the Apollo 16 regolith breccias and some of the Apollo 16 soils are immature (I_s/FeO≤30), indicating that they were exposed to the space environment for a short period of time (Fig. 2a). In contrast, although most of the Apollo 15 regolith breccias are immature, 5 samples are composed of submature regolith (30≥I_s/FeO≤60), and one is a mature regolith (60≥I_s/FeO). Half of the Apollo 15 soils are submature and half are mature.

Discussion: Although the Apollo 15 samples were produced after the same basin-forming event as the Apollo 16 samples of [1], the Apollo 15 samples represent much younger regolith. None of the Apollo 15 breccias have ages approaching the >3.4 Ga ages of the Apollo 16 ancient regolith breccias.

Apollo 15 landing site context: Most of the Apollo 15 regolith breccia samples with closure ages >1.2 Ga were collected in close proximity to impact craters, indicating that they were excavated from depth. The oldest samples (>2 Ga) were collected from the northern rim and inner wall of the ~100 m diameter Spur Crater (station 7, Figs. 1, 2b) located on a steeply sloping portion of the Apennine Front, which is likely older than the mare plains below. Most of the samples with closure ages of 1 to 2 Ga were collected at station 6 (Figs. 1, 2b) from the inner bench on the NE wall of a 12 m diameter crater. Similarly, the oldest regolith breccias from Apollo 16 were collected near South Ray Crater (680 m diameter) and may have been excavated from depth. Three regolith breccias with closure ages 1.1 to 1.7 Ga were collected near the rim of Hadley Rille, and potentially represent ejecta from small, local craters. Finally, the regolith breccias collected from the LM station all have closure ages <0.6 Ga.

Implications for lunar bombardment history: As most of the Apollo 15 regolith breccias are younger than the Apollo 16 ancient regolith breccias (Fig. 2a), they potentially provide an archive of regolith processes in the more recent past (i.e., the Eratosthenian and Copernican). Impactor fragments within these samples may offer insight to the bombardment history of the Earth-Moon system during Earth's Archean and Proterozoic. Therefore, they could provide new views of the sources of projectiles contributing to the formation of large impact basins and craters during the early evolution of life (e.g., [17]).

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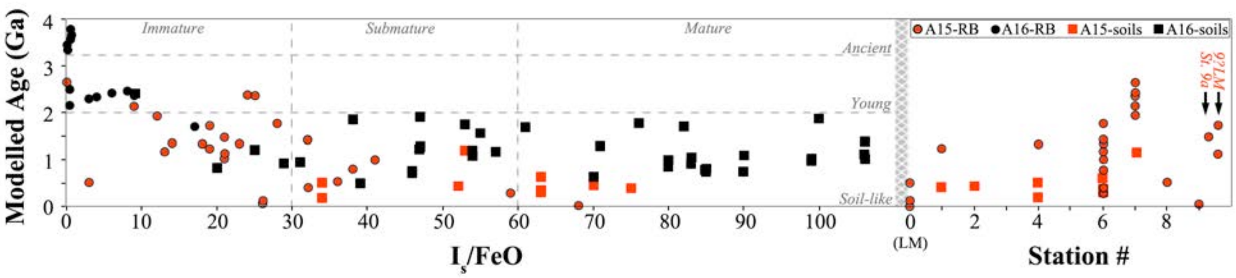

Figure 2. Comparison of the ages and exposure history (I_s/FeO index) of the Apollo 15 (Table 1, [11-15]) and Apollo 16 [10] regolith record. Apollo 15 regolith ages (Table 1) are also compared with their collection site (Fig. 1). Modeled ages represent the closure age for regolith breccias and the appearance age for soils.