COMMON 4.2 GA IMPACT AGE IN SAMPLES FROM APOLLO 16 AND 17. V.A. Fernandes[1], I. Garrick-Bethell[2], D.L. Shuster[1]and B. Weiss[2], [1]Berkeley Geochronology Center, Berkeley, CA 94709, USA (veraafernandes@yahoo.com), [2]Dep. of Earth, Atm. and Planet. Sci., MIT, 77 Massachusetts Av., Cambridge, MA 02139, USA

Introduction: The history of impactors to the Earth–Moon system both before and after the putative ~3.9 Ga heavy bombardment, is not well known. Early craters that would record this history on Earth have been erased either due to erosion or plate tectonics, while the limited number of sites visited and samples collected during the Apollo and Luna missions, and analytical challenges associated with dating impact events in general, have made the early lunar impact history difficult to estimate.

Both the lunar cataclysm theory and the continuous decline in impact events [1-5] prior to ~3.9 Ga are not well constrained and thus there is a need of additional geochronometry to better define this early period. Samples that exist in the Apollo and Luna collections potentially record this history (not only impactites but also other rocks, e.g. highlands rocks and basalts that have been affected by impact(s))-, as well as impact melts in meteorites, and in the future, samples that will be collected from more and diverse lunar sites. Here we present recently acquired $^{40}Ar/^{39}Ar$ data for age determination and thermocronology for samples from Apollo 16 and 17: 60025, 63503, 78155, 78235 and 78236.

Method and Samples: ^{40}Ar-^{39}Ar laser step-heating experiments were carried out on a total of 16 different samples from Apollo 16 (60025 and soil 63503) and Apollo 17 (78155, 78235 and 78236) (Table 1). The sample weight varied from 0.32 to 1.24 mg; In several cases the $^{40}Ar/^{39}Ar$ analyses were replicated using multilple aliquots. To minimize Ar blanks and improve temperature control, the samples were placed inside small platinum packages and heated using a diode laser and pyrometer feedback control. Ar diffusion kinetics were quantified using the ^{39}Ar and ^{37}Ar data and packet temperatures. Up to 32 heating steps were performed for each aliquot.

60025 has been described as a moderately shocked, cataclastic ferroan anorthosite [6-10]. A crystallisation age of 4.44±0.02 Ga as been determined by [11].

Soil 63503 is composed of different size clasts ranging from single mineral phases (plagioclase, pyroxene, olivine, ilmenite) to recrystallised rock (e.g. metabasalt and metanorite). At least four of the soils checked thus far by SEM do not show evidence of agglutonitic material and/or troilite. However, the clasts in these four soils show evidence of anaeling and recrystallisation. Previous Ar-Ar ages range is 1.38-4.27 Ga [12&13].

78155 is a thermally anhealed polymict breccia of anorthositic norite composition[14], previous $^{40}Ar/^{39}Ar$ data suggested an impact age of 4.22±0.04 Ga [2]

78235/78236 is a heavily shocked plutonic norite of cumulate origin with a glass coating and glass veins [15&16]. Chronology for this sample suggests a crystalisation of 4.43 ± 0.05 Ga [17] and to have been disturbed more than once (i.e. ~4.2 Ga and ~2.6 Ga, [17]).

^{40}Ar-^{39}Ar Results: The ^{40}Ar-^{39}Ar release data obtained for the 16 Apollo samples are divided into 3 main groups for ease of presentation in this abstract, data summary (error is 2σ):

63503,9, 78155,1 and 79235,139: The argon release of these samples is straightforward and shows a plateau over 90 to 95% of the ^{39}Ar-release Fig.1. The initial, low temperature steps suggest a small contribution from excess argon and are not considered for age calculation. The ages obtained are 4.210±0.180 Ga (63503,9), 4.195±0.074 Ga (averaged over 4 aliquots of 78155) and 4.188±0.074 Ga (78235, 139),.

60025, 63503,14, 63503,16, 63503,17, 63503,20 and 63503,21: The age spectra of these samples suggest that the Ar release shows two shock related phenomena, loss and implantation of argon. Further more, more than one shock event is observed from the argon release Fig.2. The initial ~50% of ^{39}Ar release are dominated by trapped $^{40}Ar/^{36}Ar$ (0.54 to 1.46) and having large apparent ages. These ages start as high as 6.0 Ga and are followed by a decrease to ages of ~3.91 Ga to ~ 4.2 Ga at intermediate temperatures. At intermediate to high temperature steps, the release forms a plateau, compriside only of radiogenic ^{40}Ar, with a constant Ca/K, a ^{39}Ar release between 23 and 53%. Two samples show evidence for only one resetting event at 4.054±0.072Ga (63503,17) and 4.251±0.046 Ga (63503,20). Samples suggesting two distinct events at intermediate (i) and high (h) temperatures. For example, sample 63503,21 high temperature age is 4.237±0.040 Ga and intermdiate temperature is 4.040±0.034 Ga (Table 1). The high-temperature plateau age (17% ^{39}Ar release) of 4.453±0.05 Ga for 63503,14 suggests this to be a preserved crystallization of the primary rock and the 4.191±0.034 Ga age over 36% of the ^{39}Ar release at intermediate indicates an impact event.

63503,1, 63503,4, 63503,11, 63503,13, 63503,15: The samples in this group, show that ~30-40% of the argon release at low temperature was disturbed by an event (i.e. impact) Fig.3. There are three impact ages suggested based on initial ^{39}Ar release, 3.345±0.084 Ga (63503,1 and 63503,15), 3.695±0.096 Ga (63503,4) and 3.866±0.098 Ga (63503,13). At intermediate to high temperature steps a well defined plateau over ~60-70% of the ^{39}Ar release and corresponding to ages of 4.188±0.074 Ga (63503, 4), 4.296±0.176 Ga (63503,13), 4.237±0.078 Ga (63503,11) and 4.211±0.045 Ga (63503,15). Sample 63503,1 shows at intermediate and high temperature steps (~51% ^{39}Ar-release) an age of 3.874±0.030 Ga, and the maximum apparent age observed for the last heating step of 4.549±0.054 Ga suggests a minimum crystallisation age for this sample.

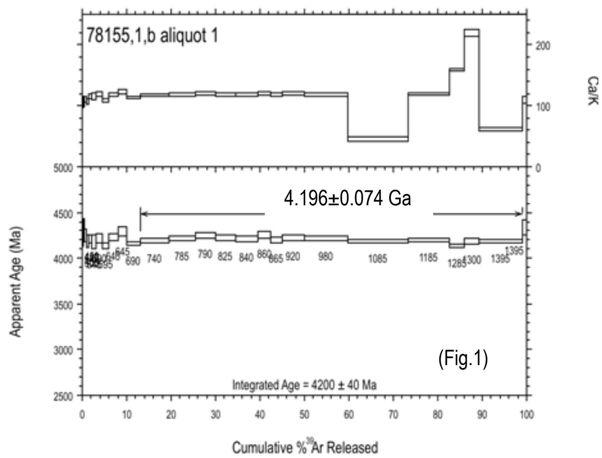

Figure 1 Apparent age vs.%^{39}Ar release for thermally anhealed polymict breccia 78155 showing an almost perfect plateau

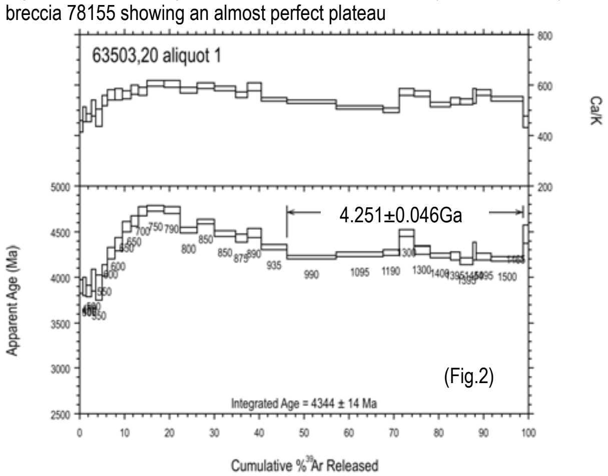

Figure 2 Apparent age vs.%^{39}Ar release for thermally anhealed regolith 63503,20. Initial ~46% of ^{39}Ar release shows the influence of excess/implanted Ar.

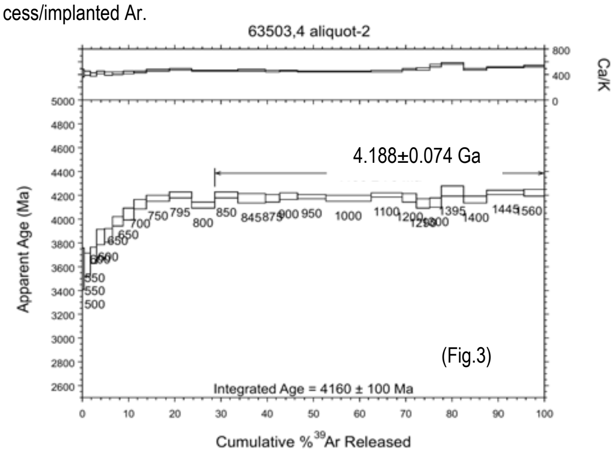

Figure 3 Apparent age vs.%^{39}Ar release for thermally anhealed regolith 63503,4 showing a partial re-setting event at ~3.7 Ga.

Conclusions: If we assume, based on petrologic information, that the ^{40}Ar/^{39}Ar ages represent the ages of impact events, the Apollo 16 and 17 samples show a similar signature for an impact event(s) at ~4.2 Ga. A similar age for breccia 67955 was recently reported by [18], and SIMS U-Pb analyses on several Apollo 14 and 17 zircons also suggest similar shock ages [19]. Thus, it is suitable to say that a significant impact event(s) occurred at ~4.2 Ga to affect not only the K-Ar system in plagioclases and pyroxenes, but also the U-Pb of zircons. The petrology and argon release of Apollo 16 and 17 samples also suggest other more recent impact events (~ 3.3 Ga, ~3.7 Ga and ~3.9 Ga). The maximum apparent age observed for the last heating step release of 4.549±0.054 Ga is within error the same as the Moon's formation age reported by [20] making this one of the oldest lunar rocks (e.g. [21]) thus far analysed……

Table1: Summary ^{40}Ar-^{39}Ar ages obtained for Apollo 16 and 17 fragments

	Early event (Ga)	Later event (Ga)	Max. age (Ga)	Sample wt (mg)
60025,1	4.260± 0.076	3.911±0.014	-	0.42
63503,4	4.188± 0.074	3.695± 0.096		1.18
63503,9	4.210±0.180	-	-	0.50
63503,11	4.237±0.078	3.306±0.194	-	0.53
63503,13	4.296±0.176	3.866±0.098	-	0.53
63503,14	4.191±0.034	-	4.453±0.050€	0.55
63503,15	4.211±0.136	3.345±0.092	-	0.50
63503,16	-	3.995±0.068	4.424±0.110$	0.65
63503,17	4.054±0.072	-	-	0.65
63503,20	4.251±0.046	-	-	0.82
63503,21	4.237±0.040	-	-	-
78155 (x4)	4.195±0.074	-	-	0.39-0.85
78235,139,1	4.188±0.074	-	-	0.64
78235,139,2	4.157±0.074	-	-	1.24
78236,18,2	4.228±0.030	3726±0.106	-	-
63503,1	3.874± 0.030	3.345± 0.084	4.549±0.054£	0.86
63503,3	3.904± 0.072	3.387± 0.162	-	0.81

€A plateau comprised of 17% ^{39}Ar release at high temperature.
$A plateau comprised of 24% ^{39}Ar release at high temperature
£Maximum apparent age comprised of the last step at high-temperature, and likely minimum crystallisation of primary rock.

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