NEWLY DETERMINED Ar/Ar AGES OF LUNAR TROCTOLITE 76535. J. Park[1,2,3], L.E. Nyquist[4], G.F. Herzog[1], B.D. Turrin[5], F.N. Lindsay[1], J.S. Delaney[1], C.C. Swisher III[5]. C.-Y. Shih[6], A. Yamaguchi[7]. [1]Dept Chem. & Chem. Biol, Rutgers Univ., Piscataway, NJ 08854 (email: jp975@rci.rutgers.edu), [2]Lunar Planet. Inst., Houston, TX 77058, [3]Kingsborough Community College of the City University of New York (CUNY), Brooklyn, NY 11235, [4]KR/NASA Johnson Space Center, Houston, TX 77058, [5]Dept. Earth Planet. Sci., Rutgers Univ., Piscataway, NJ 08854, [6]JE-23, ESCG/Jacobs Sverdrup, Houston, TX 77258, [7]Antarctic Meteorite Research Center, Natl. Inst. Polar Research, Tokyo 190-8518, Japan.

Introduction: Lunar troctolite 76535 evidently formed as a cumulate in the lunar magma ocean [e.g., 1,2]. It is an old rock with ages suggesting that petrogenesis lasted until 4.25 Ga B.P (Table 1). The mineral composition of 76535 - ~55% plagioclase (An_{96}) and 37% olivine (Fo_{88}) – makes it good subject for Ar/Ar dating, a radiometric system that generally closes at lower temperatures and hence later than do other isotopic systems. Published results of Ar/Ar dating scatter (Table 1). We report new determinations of the Ar/Ar systematics of three plagioclase separates from 76535.

Table1. Summary of radiometric age data for 76535.

System	Age (Ga)	Reference	Rem
Ar/Ar	4.246±0.018	This work	Plag
Ar/Ar	4.208±0.016	This work	Plag
Ar/Ar	4.208±0.017	This work	Plag
Ar/Ar	4.23	HunWas75 [3]	Plag
Ar/Ar	4.8	HunWas75 [3]	Ol
Ar/Ar	4.26±0.02	HusSch75 [4]	
K/Ar	4.34	Bogard74,75 [5,6]	Plag
Rb/Sr	4.57±0.07	PapWas76 [7]	
Rb/Sr	4.308±0.045	Borg13 [8]	
Rb/Sr	4.38	PreTats92 [9]	
$^{147}Sm/^{143}Nd$	4.335±0.071	Nyquist12 [10]	
$^{146}Sm/^{142}Nd$	4.439±0.022	Nyquist12 [10]	
$^{146}Sm/^{142}Nd$	4.295^{29}_{36}	Borg13 [8]	
$^{147}Sm/^{143}Nd$	4.293±11	Borg13 [8]	
$^{207}Pb/^{206}Pb$	4.226 ±0.035	PreTats92 [9]	
U/Pb	4.236±15	PreTats92 [9]	
Pb-Pb	4.375±1	Borg13 [6]	

Experimental Methods: *Samples.* We gently crushed a few mg of Troctolite 76535, and hand-picked the colorless grains. The grains' mineral identity was confirmed by Raman Spectroscopy at NASA JSC. Three samples were selected for Ar/Ar analyses at Rutgers University. 76535-21-A1: 4 grains, 2.99 mg, 76535-21-A2: 12 grains, 3.01 mg and 76535-21-B: 11 grains, 4.78 mg.

*Ar analysis:*The samples were loaded in an Al well plate, sealed in an evacuated quartz tube, and irradiated for 80 hours without Cd shielding at the USGS Triga reactor in Denver. Argon isotopes were analyzed using a modified MAP 215-50 mass spectrometer with a CO_2 laser [11, 12].

Results: *Integrated ages.* The ^{40}Ar concentrations range from ~2.77-3.31× 10^{-8} cm^3STP/g; Bogard and Nyquist [5] reported a value of ~2.85×10^{-8} cm^3STP/g. Fig. 1 shows the Ar age spectra without corrections for trapped ^{40}Ar. The integrated $^{40}Ar/^{39}Ar$ ages (Ma) for 76535-21-A1, -A2, and –B are 4.365±0.021 Ga, 4.266±0.017 Ga, and 4.365±0.021 Ga, respectively.

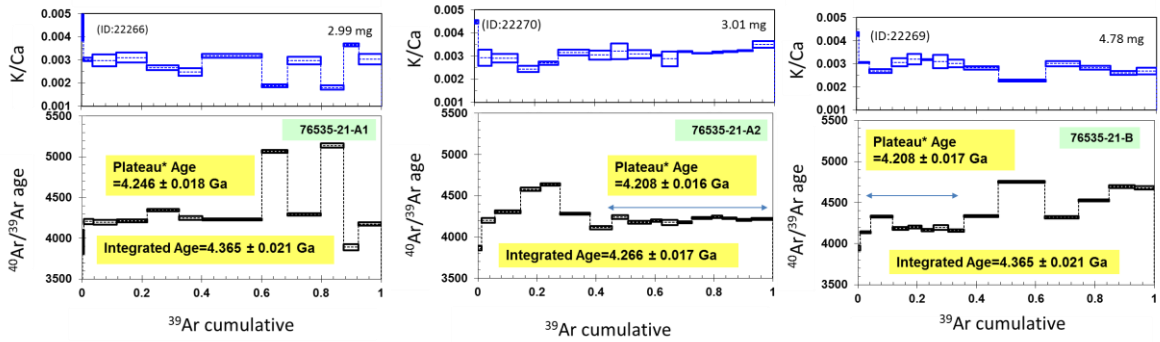
Age spectra. Like the one previously reported by [3], our Ar age spectra show large apparent age swings (Fig. 1) with several ages over 4.5 Ga. These ages may reflect ^{40}Ar redistribution from high- to low-K bearing regions. Plateau* ages (*: forced plateau) are 4.246±0.018 Ga (a few outliers fall off), 4.208±0.016 Ga (45-100% of ^{39}Ar), and 4.208±0.017 Ga (1-36% of ^{39}Ar), somewhat lower than reported by others (Table 1).

Isochrons. Isochrons for $^{40}Ar/^{36}Ar$ vs. $^{39}Ar/^{36}Ar$ were plotted (Fig. 2) after removing a cosmogenic ^{36}Ar component calculated using the measured $^{36}Ar/^{38}Ar$ ratios and empirically derived $^{38}Ar/^{36}Ar$ = 3.0, which includes the effect of reactor produced ^{38}Ar. Because of the long irradiation on the Moon (~200 Ma [6,13,14]), removing cosmogenic ^{36}Ar from trapped ^{36}Ar is important to determine the correct values of $^{40}Ar/^{36}Ar_t$ and $^{39}Ar/^{36}Ar_t$ to obtain the correct isochron age. (Here subscript-t denotes "trapped"). Fig. 2 shows the isochron age of 4.28± 0.10 Ga and intercept $(^{40}Ar/^{36}Ar)_t$ of -9.2±7.9.

Discussion and Conclusions: *Ar/Ar ages*. Although the release of Ar from age spectra appear to be complex, (e.g.,[3]) our best-defined Ar/Ar age is about ~4.21-4.28 Ga. By observing Ar/Ar age spectra, we accept that 76535 may have recorded at least two different ages. Huneke and Wasserburg [3] reported ages of ~4.23 Ga and ~4.8 Ga from plagioclase and olivine separates, respectively. Also the other radiometric ages (Table 1) vary somewhat. Some of the old Ar age steps at the lower temperature steps from –A2 and the higher temperature steps from –B may indicate the presence of trapped ^{40}Ar, not produced by in situ decay of ^{40}K, an interpretation favored by [3]. Alternatively, these complex Ar age spectra may have been caused by redistributed ^{40}Ar in a plutonc environment.

Another possibility for the variations in Ar age spectra is suggested by the petrological observations of the anorthite grains. Troctolite 76535 contains coarse grained plagioclase. The average sizes of the selected anorthite

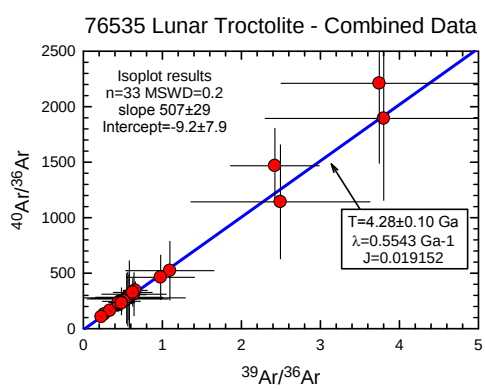
Fig.1. $^{40}Ar/^{39}Ar$ ages and K/Ca ratios of anorthite separates from 76535.



grains were ~0.5-1 mm in diameter. We investigated a few anorthite grains in detail, and a few analysed spots in the anorthite grains contained olivine and/or opx portions. In this case, some Ar extractions may have given older apparent ages as observed for the olivine data of [3]. We suggest that those extractions having low K/Ca ratios (<~0.002) and high individual ages (~5000 Ma) may have been influenced by the presence of opx (opx or ol) within the anorthite grains (Fig. 3).

Fig. 3 shows the variations in individual ages with K/Ca ratio. The highest K/Ca ratios correlate with the lowest apparent ages. These low ages are interpreted as representing some radiogenic $^{40}Ar^*$ loss from feldspar grain surfaces, and/or redistribution of $^{40}Ar^*$ from feldspars of relatively high K content to those of lower K content. That the latter is a distinct possibility is shown by the cluster of apparent ages near ~4600 Ma, and K/Ca ratios ~0.0020-0.0025.

Fig.2. Isochron plot of 76535 anorthosites with cosmogenic corrections.



Implications: The Ar/Ar ages obtained in this study are similar to those obtained in previous studies, and support an "event" in the history of 76535 at ~4.20 Ga. Nevertheless, there is a hint in the data of an older primary age that is provided by the integrated (total ^{40}Ar) ages up to ~4365 Ma, and by variations in the apparent ages of individual extractions up to "higher-than-normal"values near ~4500-4700 Ma. Although such values were characteristic of the olivine separate studied by [3], we consider it unlikely that mafic minerals would affect ~10-30% of the total ^{39}Ar release of the individual samples (Fig. 1), based on the K concentration of plagioclase and olivine [15]. Combined with the older ages determined by some other investigations (Table 1), we suggest that there is a distinct possibility that this lunar troctolite formed relatively early in a plutonic environment in the lunar crust. In this plutonic environment sub-solidus reequilibration of trace elements and $^{40}Ar^*$ could have occurred until the rock was excavated to the lunar surface where it cooled and isotopic systems closed.

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Fig.3. Plot of Ar ages vs. K/Ca ratios in 76535.