DID A TRANSIENT INCREASE IN THE IMPACT FLUX OCCUR 800 Ma AGO?

N. E. B. Zellner[1], J. W. Delano[2], T. D. Swindle[3], F. Barra[3], E. Olsen[3], D. C. B. Whittet[4] [1]Albion College, Department of Physics, Albion, MI 49224 nzellner@albion.edu, [2]New York Center for Studies on the Origin of Life, Department of Earth and Atmospheric Sciences, University at Albany (SUNY), Albany, NY 12222, [3]University of Arizona, Lunar and Planetary Laboratory, Tucson, AZ 85721, [4]New York Center for Studies on the Origin of Life, Rensselaer Polytechnic Institute, Troy, NY 12180.

Introduction: Lunar impact glasses are droplets of melt, produced by energetic impact events, which were quenched during ballistic flight. They possess the refractory element ratios of the original fused target materials at the site of impact [1]. Lunar impact glasses offer the potential not only for providing compositional information about local and remote areas of the Moon [1,2,3] but also for placing constraints on the impact history in the Earth-Moon system.

Impact events have contributed to the crustal and environmental histories of planets. Previous workers have reported $^{40}Ar/^{39}Ar$ ages of ~800 Ma on lunar samples from Apollo 12 [rock fragments; 4], Apollo 14 [impact glasses; 5], and Apollo 16 [impact glasses; 6,7]. This abstract presents additional $^{40}Ar/^{39}Ar$ ages on impact glasses from the Apollo 14 and 17 landing sites. When all of these data are viewed collectively, there is a suggestion that there may have been a transient increase in the impact flux at ~800 Ma. If correct, this increased bombardment should be kept in mind when interpreting the phylogenetic history of life on Earth during the Neoproterozoic era [8].

Sample Analysis: Impact glasses were hand-picked from regolith samples 14259,624, 64501,225, 66041,127, and 71501,262 and analyzed for Si, Ti, Al, Cr, Fe, Mn, Mg, Ca, Na, and K using a JEOL 733 electron microprobe in the Department of Earth and Environmental Sciences at Rensselaer Polytechnic Institute. Five X-ray spectrometers were tuned and calibrated for each element analyzed in the glass sample. A 15 keV electron beam with a specimen current of 50 nAmps was used. Lunar working standards were used to assess analytical precision throughout the study. Count-times of 200 seconds were used for Na and K, while count-times of 40 seconds were used for the other elements. Backgrounds were collected for every element on every analysis. Uncertainties in the measurements were usually < 3% of the amount present.

Impact glasses were subsequently irradiated and analyzed in order to determine their $^{40}Ar/^{39}Ar$ ages. Samples were irradiated in the Phoenix Ford Reactor at the University of Michigan for about 300 hours, producing J-factors of 0.05776 ± 0.00030. CaF_2 salts and MMhb-1 hornblende samples were irradiated simultaneously, the former to correct for reactor-produced interferences and the latter to determine the neutron fluence. Laser step-heating on these samples was carried out in the University of Arizona noble gas lab, using a continuous Ar-ion laser heating system. Heating steps were determined by passing a roughly-focused beam over the sample's surface. The amperage was then increased incrementally until ^{40}Ar counts from the sample peaked then decreased to no greater than background levels. In addition to system blank and interference corrections, Ar isotopes produced by cosmic ray spallation and by implantation from the solar wind were subtracted from each sample.

Results: Of the 62 glasses from the Apollo 14, 16, and 17 landing sites for which an age has been determined by these authors, 8 have diverse compositions with ages ~800 Ma (~13%), 5 have ages ~700 Ma (8%), and 4 have ages ~3730 Ma [6.5%; 3]. Table 1 shows the ~800 Ma ages with 1σ uncertainty for the lunar impact glasses discussed in this abstract. Figure 1 shows the atomic proportions of refractory lithophile elements in lunar impact glasses from the Apollo 14, 16, and 17 landing sites analyzed by these authors, along with samples from Apollo 12 [800 Ma; 4] and Apollo 16 [790 Ma; 7]. Those glasses in Figure 1 having compositions that differ from the local regoliths are interpreted as having been ballistically transported from other regions of the Moon by (large) impact events. In contrast, glasses having compositions of local regoliths are interpreted as having been formed during (small) local impact events.

Figure 2 shows the range of Al_2O_3 (wt%) abundances in impact glasses and other lunar samples having Ar-Ar ages in the interval of ~920 - ~500 Ma. Note that impact glasses occur with high frequency and diverse compositions at ~800 Ma. Note also that these ~800 Ma samples occur at all 4 of these widely separated landing sites. Figure 2 shows that the largest compositional range of local and exotic samples occurs at ~800 Ma, which is also similar to the best current estimate for the age of the Copernicus impact event [~800±15 Ma; 4,9].

Conclusion: The compositional diversity of ~800 Ma impact glasses and other lunar samples, the majority of which were not derived by local impact events, from four Apollo landing sites is consistent with there having been numerous impact events, many of which were large enough to transport these samples to compositionally different regions of the Moon. The higher frequency of impact glasses with this age is also consistent with a transient increase in the impact flux at this time. Perhaps the Copernicus impact event was only one of numerous large events (and many small local events) that occurred, with the Asteroid Belt as the source of the impactors [10].

Acknowledgements: This work has been supported by a grant from the NASA Exobiology Program (NAG5-7598) to the New York Center for Studies on the Origin of Life, a NASA Specialized Center of Research and Training.

References: [1] Delano, J.W. (1991) *GCA*, **55**, 3019-3029. [2] Zellner *et al.* (2002) *JGR*, **107(E11)**, 5102, doi:10.1029/2001JE001800. [3] Delano *et al.* (2005) *MAPS in review*. [4] Barra *et al.* (2004) *LPSC 35*, 1365.pdf. [5] Culler *et al.* (2000) *Science*, **287**, 1785-1788. [6] Zellner *et al.* (2003) *LPSC 34*, 1157.pdf. [7] Borchardt *et al.* (1986) *PLPSC 17th*, p. E43-E54. [8] Blair and Hedges (2005) *Molecular Biol. Evol.*, **22(11)**, 2275-2284. [9] Bogard *et al.* (1994) *GCA*, **58**, 3093-3100. [10] Kring *et al.* (1996) *JGR*, **101(E12)**, 29353-29371.

Table 1. Ar-Ar ages of lunar impact glasses

Sample # (Apollo site)	Age (Ma)	Uncertainty (1σ)	% ^{39}Ar released	# extraction steps
254 (16)	849	6	87.4	4
505 (16)	824	32	97.8	2
251 (16)	805	87	68.4	3
90 (14)	783	2	86.9	6
100 (14)	783	38	99.9	1
239 (16)	777	6	75.7	7
311 (17)	774	5	96.2	4
135 (14)	769	3	84.5	5

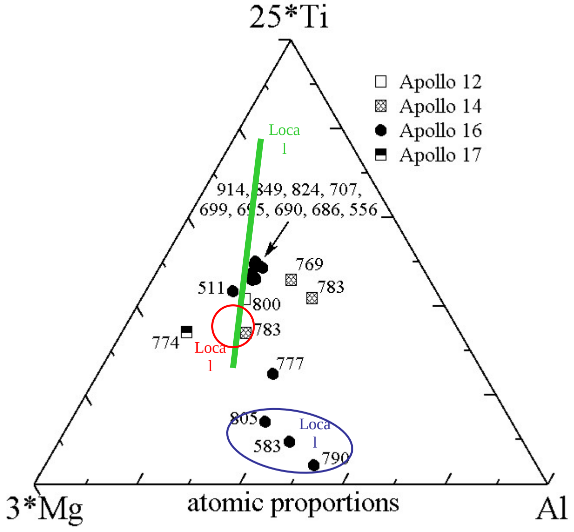

Figure 1. Ternary diagram showing the atomic proportions of refractory lithophile elements in the lunar samples discussed in this abstract. The numbers adjacent to each point are the Ar-Ar ages (Ma). Nine KREEPy glasses with ages ~920 - ~550 Ma are identified by the arrow. Local regolith compositions at Apollo 14 (circle), Apollo 16 (ellipse), and Apollo 17 (bold line) are shown for comparison with the compositions of the impact glasses.

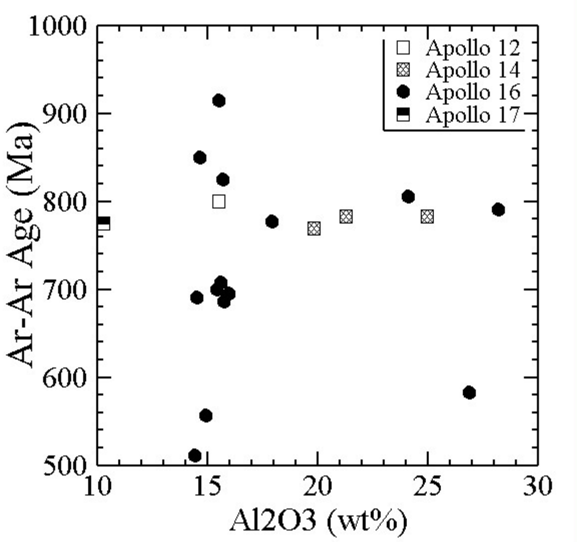

Figure 2. Diagram showing the range of Al_2O_3 abundances in impact glasses and other lunar samples with ages in the range of ~920 - ~500 Ma. Note that compositionally diverse samples with ages of ~800 Ma occur at the four widely separated Apollo landing sites.